This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

GODFREY LOWELL CABOT SCIENCE LIBRARY
of the Harvard College Library

This book is
FRAGILE
and circulates only with permission.
Please handle with care
and consult a staff member
before photocopying.

Thanks for your help in preserving
Harvard's library collections.

Dell
Ln

\$4.50

[illegible]

OBSERVATIONS

ON

LIMES, CALCAREOUS CEMENTS,

MORTARS, STUCCOS AND CONCRETE,

AND ON

PUZZOLANAS, NATURAL AND ARTIFICIAL;

TOGETHER WITH

RULES DEDUCED FROM NUMEROUS EXPERIMENTS

FOR MAKING

AN ARTIFICIAL WATER CEMENT,

EQUAL IN EFFICIENCY TO

THE BEST NATURAL CEMENTS OF ENGLAND,

IMPROPERLY TERMED ROMAN CEMENTS;

AND AN ABSTRACT OF THE OPINIONS OF FORMER AUTHORS
ON THE SAME SUBJECTS.

BY MAJOR-GENERAL SIR C. W. PASLEY, K.C.B.
FROM THE CORPS OF ROYAL ENGINEERS,
F.R.S., F.R.A.S., F.G.S., D.C.L., &c.
HONORARY MEMBER OF THE INSTITUTION OF CIVIL ENGINEERS,
AND OF THE ROYAL INSTITUTE OF BRITISH ARCHITECTS.

SECOND EDITION, PART I.

LONDON:
JOHN WEALE, ARCHITECTURAL LIBRARY,
59, HIGH HOLBORN.
1847.

Eng 638.47

MAR -6 1912
HARVARD UNIVERSITY
DEPARTMENT OF ENGINEERING.

PRINTED BY W. HUGHES,
KING'S HEAD COURT, GOUGH SQUARE.

PREFACE TO THE FIRST EDITION.

THE first sheets of the present work were sent to press in May, 1836, so that the unusual period of nearly two years and a half has elapsed between the commencement and the completion of printing it. This was owing to new questions concerning the properties of cements continually suggesting themselves, seldom occupying less than a fortnight and sometimes three months, or even more, before they could be properly decided; besides which, time was repeatedly lost by unforeseen failures in our apparatus, which required not only the defective parts of the wood or ironwork to be replaced, but sometimes also spoiled the cements that were to be experimented upon, the replacing of which, if artificial, was a work of time. During this period also, as our views became more enlarged, the common modes of experimenting on the comparative strength of cements and mortars, which we had at first adopted, appeared to be unsatisfactory, so that in addition to these, we had recourse to a new method for ascertaining their comparative adhesiveness to bricks and stones, which is in fact their most important property, but to which little or no attention had been paid by former writers. This also was of course a cause of delay.

As the whole of the opinions stated in this Treatise were deduced from personal observation, or from the successive experiments alluded to, with the exception of those founded on, or corroborated by, some important facts extracted from a paper of Mr. Timperley, published in the first volume of the 'Transactions of the Institution of Civil Engineers;' and as these experiments occupied so long a period of time, and the book was printed in portions, during the intervals between successive experiments, it cannot boast of such a methodical arrangement, as might have been adopted, had every experiment recorded in it been tried, before the first sheet was sent to press. Hence it was thought desirable, in order to compensate this want of arrangement by facility of reference, to make the Table of Contents more ample than usual, so as to form a sort of abridgement of the work itself, rather than a mere outline of the titles of the subjects discussed.

In this Treatise, the various properties of limes, of calcareous mortars and cements, as well as of puzzolanas, have been discussed in the amplest manner, and reduced to a system, no part of which, however, has been founded on mere hypothesis.

I trust that a good deal of new information will be found in the following pages, upon a subject of immense importance to mankind, and that the principles developed in it will prevent such crude notions respecting calcareous mortars and cements from being adopted in future, as have occasionally caused the gradual and sometimes even the sudden ruin of the locks of canals, wharf and dock walls, and other pieces of brickwork or masonry, exposed to the action of water; for although sound principles have been acted upon by writers as well as practical men, how is the young student to decide, when he reads the discordant opinions of Semple, Smeaton, and Higgins, in this country, and of Belidor, Loriot, De la Faye, Vicat, and Treussart, in France, all maintained with equal confidence; and when he finds no less discordant opinions maintained with no less confidence by practical men, trusting to what they call experience, which may be very limited, for unless a man of business be also a man of research, he cannot know what has been done in foreign countries, or even in distant parts of his own.

To do away this uncertainty, I have endeavoured to point out such modes of experimenting and of personal observation, as will enable an intelligent person, who has no experience of his own, to decide justly between the various sorts of calcareous mortars and cements, that may be held out by their respective partizans as being the best, or if not absolutely the best, as being the most expedient in an economical point of view; which last consideration has caused the weaker water limes and sometimes even common lime, such as the chalk lime of the South of England, to be used for the brickwork of masonry of works of the above-mentioned description, than which there cannot be a more mistaken economy, because the mortars of these limes are absolutely unfit to resist the action of water, and cannot insure the stability of walls built with them, and exposed to that action, for any length of time.

Of all the authors who have investigated the properties of calcareous mortars and cements, from time immemorial to the present day, our countryman Smeaton appears to me to have the greatest merit; for although he found out no new cement himself, he was the first who discovered, in or soon after the year 1756, that the real cause of the water-setting properties of limes and cements consisted in a combination of clay with the carbonate of lime; in consequence of having ascertained by a very simple sort of chemical analysis, that there was a proportion of the former ingredient in all the natural lime stones, which, on being calcined, developed that highly important quality, without which, walls exposed to water go to pieces, and those exposed to air and weather only, are comparatively of inferior strength. By this memorable discovery, Smeaton overset the prejudices of more than 2000 years, adopted by all former writers, from Vitruvius in ancient Rome, to Belidor in France, and Semple in this country, who agreed in maintaining that the superiority of lime consisted in the hardness and whiteness of the stone, the former of which may or may not be accompanied by water-setting or powerfully cementing properties, and the latter of which is absolutely incompatible with them. The new principle laid down by Smeaton, the truth of which has recently been admitted by the most enlightened chemists and engineers of Europe, was the basis of the attempts made by Dr. John, at Berlin, and by M. Vicat, in France, to form an artificial water lime or hydraulic lime, in 1818, and of mine to form an artificial water cement at Chatham, in 1826, to which I was led by the perusal of Smeaton's observations, without knowing any thing of the previous labours of those gentlemen, on the Continent, or of Mr. Frost, the acknowledged imitator of M. Vicat, in this country.

The natural cements of England, most improperly and absurdly termed Roman Cement, though the discovery of their properties and use is as much a modern discovery as the steam engine, and of more recent date, possess an infinite superiority over all other hydraulic mortars, not excepting puzzolana, which in combination with lime formed the strongest cement that the Romans were acquainted with.

First discovered by Parker in 1796, our English cements are now prepared for use by a great number of manufacturers, some of whom may be depended upon as never offering a bad article for sale, and any individual who applies to them will be sure to have it good; but in the public departments, it is so common to advertise for tenders for building materials and to accept the lowest, that it tempts unprincipled men, who gain such contracts by offering to supply them at a lower price than would compensate the fair dealer, to endeavour to pass off not merely an inferior but an adulterated article upon the Receiving Officers, of which I have known an instance at Chatham. This induced me to endeavour to lay down rules for judging of the quality of cement offered for sale, and for ascertaining whether it has been adulterated or not; by attending to which, the most inexperienced person may easily detect such frauds, in twenty-four hours or even less.

Instructions have also been given, by which Officers of Engineers or others, stationed in the colonies or employed in exploring some new country, will be enabled to judge whether a calcareous stone whose properties have not before been ascertained is a water cement, a water lime, or a common lime.

Moreover, as it is very difficult to decide upon the value of different calcareous cements and mortars by building portions of walls with them, which would not only require an inconvenient length of time to compare them, but would be liable to great uncertainty, rules have been laid down, by which their comparative strength may be judged of experimentally, in a short space of time, such as ten days, with very little trouble and with the greatest accuracy; that is, if I am right in the opinion formed by me after the continual experiments of many years; namely, that those cements and mortars which set the soonest under water, and which are found to possess the greatest resistance and adhesiveness at the end of that period, will also prove the most durable, and will retain the same comparative superiority for any length of time. These rules, if correct, as I trust they are, will obviously be of the greatest importance, by enabling an Engineer to make a judicious choice between two sorts of cement or of mortar, both apparently good, but between which there may in reality be a considerable difference, which no other mode of comparison can detect so conveniently or with so much accuracy.

The properties of cements first attracted my notice most particularly, so that when, after many previous failures, I succeeded in forming an efficient artificial cement on a great scale in 1830, I took very little notice of limes and none of puzzolana, in a pamphlet printed by me in that same year, which contained Observations on the Natural Water Cements of England, with a description of my Artificial Cement made in imitation of them.

This pamphlet was sent, by authority of the Master-General and Board of Ordnance, to all the Royal Engineer Stations at home and abroad, and by the Court of Directors of the East India Company to all their Engineer Stations in India, and copies of it were presented by me to various scientific societies, as well as to several private friends. I discovered, however, on resuming the same subject six years afterwards, that my artificial water cement of 1830 was not the strongest that could have been made of the same ingredients, as will be seen by a perusal of the present Treatise.

That the artificial cement, more recently made at the Royal Engineer Establishment, in the years 1836, 1837, and 1838, is equal in efficiency to the best natural water cements of England, as set forth in the title-page of this work, has been fully proved by numerous experiments, tried not only in presence of all the Royal and Honourable East India Company's Engineer Officers attending this establishment, but also of Officers of other regiments and corps in the garrison of Chatham, as well as of other Gentlemen, and of Clerks of Works, Builders, and Artificers, whom I made a point of inviting to attend, as I wished to make my experiments as public as possible. The natural English cements were either supplied by Messrs. Francis and Co., of Vauxhall, or from Her Majesty's Dock-yard at Sheerness; both of excellent quality, and made, according to custom, of a mixture of calcined Harwich and Sheppy stones, which are better than either of those cements used singly. In such experiments as were not tried for the purpose of ascertaining comparative strength, but for investigating the general properties of water cements, whenever the particular sort experimented upon is not specified, let it be understood that Messrs. Francis's cement was used.

Other experiments, recorded in the following Treatise, have established an important fact before considered doubtful; namely, that cement is no less suitable for masonry, composed of the hardest and heaviest stones, than for brickwork, as was proved by the remarkable circumstance of a Bramley-fall stone breaking before the cement joint which united it to another large stone of the same kind gave way.

That a few courses of brickwork and cement bond, aided by hoop-iron in the joints, may supersede the necessity of chain timbers and bond timbers of all descriptions in the walls of buildings, as well as of wooden lintels over the openings of doors and windows and of bressummers over shop fronts, had been fully proved by the experimental brick beams of Mr. Brunel and of Messrs. Francis and Co.; but as their experiments left the comparative importance of the cement and of the hoop-iron bond doubtful, I was induced to build three experimental brick beams: one with cement alone, another with cement and hoop-iron bond, and a third with Halling lime mortar and hoop-iron bond; which on being all broken down fifty days afterwards, proved the vast importance of the hoop-iron bond, without which the brick and cement beam had comparatively very little resistance, and the brick and mortar beam would have had none. The practicability of executing domes or roofs with brickwork and cement, in forms absolutely impossible with the best lime mortar, was also proved by an interesting experiment.

In 1836, when the first sheets of this work were sent to press, a sort of enthusiasm prevailed in favour of concrete, especially when moulded into artificial stone, which induced me to experiment upon the resistance of small square prisms of artificial stone made of various limes and cements, mixed with different proportions of sand and gravel, after allowing them sufficient time to set. The extreme weakness of these experimental prisms convinced me that concrete was of very inferior importance, except when used in mass for foundations or for backing; to which Sir Robert Smirke, who first introduced the use of it in this country, very judiciously confined it. The unfavourable impression as to the value of artificial stone produced by our experiments at Chatham, has been confirmed on a great scale, by the failure of the external surface of the concrete docks and wharf walls in Her Majesty's Dock-yards at this place and at Woolwich; and even for foundations it requires to be used with judgment, and ought greatly to exceed in area the base of the walls to be supported by it: otherwise it may settle unequally and crack, as was the case in the experimental concrete casemate built at Woolwich; or it may sink to a considerable depth in soft soil, as was the case with the concrete wharf wall built by Mr. Ranger, by direction of the then Admiralty Architect, at the north extremity of Chatham Dock-yard, which has sunk about one foot deep in the mud since it was first built; and which, from the nature of its profile, combined with this deficiency of base, would have capsized and fallen into the Medway, if it had not been afterwards secured by iron bars and pieces of chain cable acting as land-ties, and fixed to piles driven at some distance in rear of it. *

In respect to water limes and water mortars, or hydraulic limes or hydraulic mortars, as the French term them, I have tried fewer experiments; the results of which however have convinced me that the opinion of Smeaton, since generally adopted, that the Aberthaw

---

* This wall escaped my observation, until the whole of my Treatise was printed, otherwise I should have noticed it in the body of the work. The concrete casemate at Woolwich was described in Article 32 and its note; and its failure from unequal settlement in the note to Article 33.

or blue lias is far the strongest of our English limes, is perfectly correct. Indeed it seems to possess rather greater strength than he gave it credit for, when he considered it necessary to mix it with puzzolana; for I have found in confirmation of the efficiency of the system, since adopted for the masonry of several important works, and amongst others for that of the celebrated Menai Bridge, that the mortar of this lime will set on being immersed, whereas the mortars of all other English limes that I have experimented upon, remain in a state of pulp under water, unless improved by the addition of a proportion of puzzolana. But this substance, as imported from Italy, being too expensive to compete with the blue lias lime mortar, the only resource for making the other limes of England available for works exposed to the action of the water, at a moderate expense, appears to be the use of artificial puzzolana, made by calcining the blue clay of the Medway, or any other impalpable clay, whether alluvial or fossile. My own experiments induce me to put great confidence in this expedient, in which however there is nothing original, because puzzolanas both natural and artificial have been in common use in the South of Europe since the time of the Romans, though the latter have been little used in this country, and the former I believe not at all until Smeaton first introduced it about 80 years ago.

The subject of cements having frequently been discussed within the last ten years at the Institution of Civil Engineers, where Mr. Frost and I, when present on those occasions, always explained our respective proceedings to the members, it was suggested to me that if the Treatise, which I then announced my intention of publishing, should take a comprehensive view of the whole subject of limes and mortars also, it would be more useful to practical men than if confined to observations on natural and artificial water cements only, like my pamphlet of 1830. In compliance, therefore, with what appeared to be the wish of several members of that excellent and most liberal institution, I have enlarged more upon limes, mortars, and puzzolanas in the body of my Treatise than I had at first intended to do; and, in deference also to their opinion, I have added in the Appendix an abstract of the writings and proceedings of the most eminent British and Foreign authors on the same subjects, that is, of the more modern ones; for every author on limes and mortars that I have met with followed the authority of Vitruvius until after the middle of the last century, when Smeaton came into the field and pointed out the inaccuracy of his doctrines, in the same manner as Lord Bacon had set aside the implicit belief in the doctrines of Aristotle in matters of philosophy.

Of the foreign writers that I have met with, M. Vicat, and his countryman, General Treussart, of the French Engineers, are far the most distinguished, as they have both carried their experimental researches into the properties and use of hydraulic and common limes, and of the various mortars that may be made, by mixing them with sand alone or with puzzolana or trass, natural or artificial, with and without sand, in numerous combinations, to a far greater extent than any former writers or practical men had ever done; and therefore it must be acknowledged, how much not only their own countrymen but other nations are indebted to them for the information contained in their respective works. But of the two, M. Vicat's writings, appear to have made the greatest impression in France, probably from the circumstance of his having been prior to General Treussart, so that he was the first to draw general attention to the great importance of hydraulic limes and mortars in that country.

They are both equally satisfactory in their experiments as to the hydraulic powers of different mortars, which they estimate by the same mode; but neither of them has attempted to ascertain the adhesiveness of their experimental mortars to stones or bricks, which, as I said before, is of much more importance than their resistance. Upon this last property, however, both M. Vicat and General Treussart have founded their opinions of the comparative strength of different mortars possessed of the same water-setting powers. On perusing their proceedings with attention, M. Vicat's experiments on this point appear to me so very unsatisfactory that I cannot help giving the preference to those of the General, which carry conviction along with them, being simple in their nature, and all described in the clearest manner, and perfectly congruous and consistent with each other. Whenever the opinions of these two gentlemen, or of any other authors, native or foreign, noticed in the Appendix, differ essentially from mine, I have not failed to remark upon them; always stating, however, whether I dissented in consequence of their being contradicted by the results of my own experiments, or merely as a matter of doubt or of private opinion.

There seems reason to believe, that the proper mode of preparing and of using cement could not have been understood in France, when M. Vicat and General Treussart published, otherwise they never would have undervalued it in the extraordinary manner they have both done, by declaring that they considered it much inferior to the hydraulic limes which they experimented upon. This error, for I do not scruple to pronounce it such, can only have arisen from their having treated their cements and their limes in the same manner, which could not fail to spoil the former, as will be acknowledged by any English builder or workman who has been in the habit of working with both.

M. Vicat, in particular, goes so far in depreciation of cement as to say, that although a vast quantity of it is now employed in and near London, it will gradually be disused as soon as the hydraulic limes shall be better known and appreciated in England. Nothing appears to me to be more unlikely than that this prediction will ever be verified. The Aberthaw, or blue lias lime, one of the strongest limes in the world, was and is well known in England; but as hydraulic mortar, it was immediately superseded by cement for all private works of importance, as soon as the latter came into the London market, although cement was then sold under Parker's patent at a much higher price in comparison with lime than has been customary since. Now as there was in those days, a much greater difficulty in prevailing on the public to adopt any thing new, than there is at present, nothing can be more conclusive than the above fact; for it must be evident, that private individuals, who had occcasion to build a wharf on their premises, would never have put themselves to a greater additional expense, by using this new cement in preference to the limes formerly in use, unless it had possessed a most decided superiority over the latter. In the public works of this country, on the contrary, whether executed by Government or by great commercial companies, cement has been less employed even for brickwork by the Engineers intrusted with the direction of them; and in masonry it has never been used at all, in consequence of a strong prejudice prevailing against it, as being altogether unfit for connecting large stones, which I feel confident that our experiments at Chatham will tend to remove. In the mean time, the wharf or dock walls of the great public works alluded to have either been built with the mortar, of what was considered the best water lime that could most conveniently be procured near the spot, or with mortar improved by the addition of puzzolana, in imitation of Smeaton's example, though not of the principle he acted upon, which was to use the best hydraulic mortar, that he was able to form by a combination of the most suitable ingredients known in his time. He found that this consisted in a mixture of puzzolana with blue lias lime, because the admirable properties of the English cements had not yet been discovered. If they had, I have no doubt that he would have used them for the construction of the Edystone Lighthouse, in preference to every other sort of mortar; and, by so doing, he might have dispensed with some of the very ingenious but expensive expedients, adopted by him for bonding all his stones together. To conclude, so far from assenting to M. Vicat's opinion, I am persuaded that the use of cement is not only increasing in England, but that it will in time supersede the most approved hydraulic mortars in other countries also, for works of importance exposed to the violent action of water.

C. W. PASLEY.

Royal Engineer Establishment, Chatham,
17th September, 1838.

ADVERTISEMENT TO THE SECOND EDITION.

A SECOND EDITION of this Treatise has been required for several years past, but the Author could not spare time to revise it till now. The first Part of the work only is offered to the public at present; the second Part will follow in a few months, with the Table of Contents for the whole. In the mean time, he has been gratified to find that his labours have not been thrown away, inasmuch as the opinion he advanced—that artificial cements, equal or little inferior to the best cements of nature, might be made with profit to themselves and benefit to the public by any manufacturers, who might think proper to adopt the principles first developed and the rules laid down by him—has since been proved to be correct. When he first published his researches on the subject, all the previous attempts to make a good artificial cement in this country had so far failed, that only one sort, that prepared by Mr. Frost, had found its way into the market, which was of inferior quality, owing chiefly to certain defects in the mode of preparing the ingredients, pointed out in the First Edition of this work. At present there are three manufactories of artificial cement in England, which have all been used more or less extensively in works of importance, and have given satisfaction; viz., first, that of Messrs. John B. White and Sons, in the parish of Swanscomb, Kent, the present proprietors of Mr. Frost's works, who, after gradually relinquishing the objectionable parts of his process, have succeeded in making a good artificial cement, which they call their PORTLAND CEMENT, by a mixture of chalk found on their own premises with the blue clay of the Medway; secondly, that of Messrs. Evans and Nicholson, of Manchester, who make an artificial cement, which has been called the PATENT LITHIC CEMENT, with the very same ingredients, and in the same proportions nearly, that were used in the Author's experiments, but the most important of which is obtained in a round-about manner from the residual matters or waste of certain chemical works, instead of working with natural substances; thirdly, that of Mr. Richard Greaves, of Stratford-upon-Avon, who makes a powerful water cement, which he calls BLUE LIAS CEMENT, by mixing a proportion of indurated clay or shale with the excellent blue lias lime of that neighourhood, both of which are found in the same quarries; the former being previously broken and ground, and the latter burned and slaked, which is absolutely necessary in making an artificial cement from any of the hard lime stones.

The success of this process, as a commercial undertaking, though the most expensive of all that were suggested in the First Edition of this work, is therefore peculiarly satisfactory, considering the great importance of good water cement, and the probability of the natural cement stones of this country, which are only found in certain localities, becoming unequal to the demand, or scarcer than they are at present.

C. W. PASLEY.

London, 9*th August*, 1847.

OBSERVATIONS,

&c.

PRELIMINARY OBSERVATIONS, AND GENERAL STATEMENT OF THE COURSE OF EXPERIMENTS PURSUED.

(1) In 1826, in consequence of having received an order the year before, from his Grace the Duke of Wellington, then Master-General of the Ordnance, that Practical Architecture was, in future, to form a part of the Course of Instruction for the Junior Officers of the Corps of Royal Engineers, attending the Establishment at Chatham, under my direction; I was induced to investigate the properties of water cements and limes, and adopted a very simple and expeditious mode of testing them; and afterwards I tried a great number of experiments, in hopes of obtaining an artificial cement from a mixture of chalk and clay. The clay experimented upon was an excellent brick-loam from Darland, in that neighbourhood, which I was induced to use in preference to any other, in consequence of the celebrated Smeaton, in his researches into the qualities of lime stones, having declared that those adapted for building under water were all composed of a mixture of lime and of a clay suited for brickmaking;* so much so, that after dissolving the lime out of several of those stones, by an acid, he found the residue to be clay of such a quality, that on being burned, it was converted into a sound red brick, which experiment of Smeaton I had myself also verified. But after the efforts of several months, all my experiments with chalk and brick-loam having completely failed, I gave up the pursuit, under the impression, however, that the thing was practicable, and that it would or might be done hereafter by a person more skilful in chemistry than myself.

---

* See Smeaton's Narrative of the Building, &c., of the Edystone Lighthouse, book iii. chap. 4.

(2) In 1828, my Friend and Brother Officer Major Reid* having come to reside at Chatham for a few months, chiefly from the interest he took in the Architectural Course, then in progress, requested me to show him not only the mode I had adopted of testing the natural cement and lime stones, which had proved perfectly satisfactory, but also in what manner I had attempted to form an artificial cement. I was at first reluctant to repeat any of those experiments, which I told him could only lead to certain failure, but on his expressing a strong wish to see them notwithstanding, I complied with his request; and as my stock of brick-loam from Darland was at this time expended, and that place was nearly two miles distant, a different clay was used in lieu of it, which to our mutual surprise and satisfaction formed an excellent artificial water cement. This unexpected success was owing to my having given directions to a soldier, whom I employed in such experiments, to mix two parts of pulverized chalk and one part of clay together, without specifying what kind of clay, and he fortunately selected the blue clay of the Medway as being the nearest to the spot, and which on this account had been used by the Corps, to secure the powder-hoses of our experimental military mines, when prepared for explosion.

(3) Mere accident having thus led me to resume under more favourable circumstances an investigation, that I had entirely abandoned as hopeless, and having soon after discovered what I supposed to be the cause of the failure of the brown and the success of the blue clay, I proceeded to try many hundred experiments of a satisfactory nature; and have succeeded in rivalling the most powerful natural water cements by a great number of artificial compounds, which appear to possess the same properties, but are generally of a much lighter colour. I was engaged in this pursuit for more than three years; in which the winter months were chiefly devoted to experiments on a small scale, tried generally in crucibles in a common fire-place, whilst the summer months were employed in burning my artificial cement in sufficient quantities for the practical purposes of building. My first efforts to make good cement on a great scale in the summer of 1829 failed, in consequence of some very extraordinary and unforeseen difficulties, that had not come to light in working on a smaller scale; but in the summer of 1830, these difficulties were surmounted, and my artificial cement has since been applied with success to all the

---

* Now Lieut.-Colonel, and Governor of Bermuda.

practical purposes to which the natural cements have as yet been used, of which conspicuous and satisfactory specimens may be seen at or near Brompton Barracks, Chatham. Two small brick tanks or reservoirs have been lined with it, both perfectly water-tight, one in a garden attached to the Barracks, another at a little distance from them, near some cottages occupied by married Soldiers of the Corps. It has been applied as stucco to the brickwork of all the gateways of the Barracks, and to the coating of two brick sentry boxes at the principal entrance. It has been run in moulds into the form of ornamental vases and chimney pots. It has stood the severest frosts; and in tenacity it was found rather superior to Harwich cement of good quality, as was proved by experiments that will hereafter be noticed.

(4) At the period alluded to, I knew nothing of the researches of M. Vicat, in France, who had previously succeeded in obtaining, by artificial means, limes having what the French term 'hydraulic properties,' which correspond with what are styled the water limes of this country. And it was not till several years afterwards, that I heard of a patent having been taken out in 1818, by Mr. Maurice St. Ledger, of Camberwell, for making a lime with a mixture of pulverized chalk, or other lime stone, and clay: but I was well acquainted, and in occasional communication from time to time, with Mr. Frost, who had actually established a manufactory of artificial stone and cement near Northfleet, before I commenced my operations. I shall hereafter briefly describe the proceedings of these gentlemen, and also of General Treussart, in France, so far as they have come to my knowledge. In the mean time I shall explain my own, commencing with some preliminary observations on the distinction between the various kinds of stones that supply lime, plaster, or cement, for building.

OF THE PURE LIME STONES, AND OF THE MORTAR THAT MAY BE MADE WITH THEM.

(5) The pure limes are those which consist entirely of carbonate of lime, that is, of lime combined with carbonic acid gas or fixed air, in the proportion of about five parts by weight of the former to four of the latter; and they are all white, such as pure chalk, and the Carrara marble used by Statuaries, which are the purest lime stones in nature.

When a small piece of chalk or white marble is put into a glass of muriatic or nitric acid, diluted by about an equal quantity of water, the carbonic acid gas is expelled violently with great effervescence, and the lime is entirely dissolved in the liquor, which consequently retains its original colour and clearness. The same effect will be produced by these acids in their pure or concentrated state, but it is best to dilute them.

(6) When chalk or white marble are exposed to a strong red heat for a sufficient time, as in the process of being burned in a kiln, the carbonic acid gas is also driven off, and the stone is converted into *Quick Lime,* in which state it will have lost about four-ninths of its weight, and if a fragment of it be now dropped into a glass of the diluted acids before mentioned, no effervescence will take place. The quick lime thus produced is capable of *slaking,* that is, if a certain quantity of water be added to it, it will fall to pieces with great heat, assuming the form of a fine white powder, which, after being sifted, is mixed up with sand and an additional quantity of water, to form mortar for building.

Quick lime will also gradually slake by exposure to the atmosphere, especially in damp weather, and in this case the heat, which we may presume always attends the process of slaking, is not perceptible.

The pure, or white chalk, which is the *Upper Chalk* of the Geologists, is always found mixed with flints, which are thrown aside in preparing it for the kiln, but occasionally there are also small portions of other silicious matter imbedded in the same chalk, which cannot be detected until after it is burned, and are then known by their not slaking. These pieces, technically termed *Core,* which will not pass through the sieve, when the lime is slaked for making mortar, are always thrown away. Portions of the pure chalk itself are also rejected as core, if they will not slake from having been underburned, which sometimes happens.

The powder formed by slaking quick lime with water is called *Hydrate of Lime,* as it consists at first of a mixture of solidified water and of quick lime. One cubic foot of chalk lime, burned in pieces not exceeding the size of a man's fist, weighs on an average 35 ℔s., and is consequently the produce of about 63 ℔s. of dry chalk.* When pounded dry, without being slaked, it will occupy less than a cubic foot in the state of quick-lime powder, but when gradually slaked with the proper quantity of water, which takes about two hours and a half, it will fill a space of more than a cubic foot and a half, and by the solidification of the water during this process, its weight will also have increased, but not in so great a proportion.

---

* One cubic foot of solid chalk, such as is obtained near Chatham, weighs, when perfectly dry, about 90 ℔s., but on breaking it into small pieces for burning, a cubic foot measure will only contain about 63 ℔s. of the same chalk of fair level measure.

(7) When pure lime, after being burned, is pounded and made up into a ball with water, it becomes very hot in a few minutes, and bursts with a kind of explosion into several pieces, which are sometimes thrown to a little distance. If such a ball be put into a cup full of water, it also generally bursts, but much less violently, and the pieces generally swell in the water. Sometimes it swells into a soft pulpy mass, of a much larger size, which eventually falls to pieces, being first diffused through, and discolouring the water, which it renders warm, if the cup be small.

The smallest proportion of water capable of forming a ball with quick-lime powder is one part of the former to three of the latter by measure. On increasing the comparative dose of water, by using one measure of this fluid to only two measures of quick lime, a much thinner paste will be produced, but this also will form a ball, which will fall to pieces like the former, though not so soon nor so violently.

(8) It was before stated, that well-burned lime, fresh from the kiln, contains no carbonic acid gas, and when first slaked it seems for the moment to be still free from it, or nearly so; but it begins to imbibe this gas immediately afterwards, which may be known by its effervescing in the diluted acids, and in process of time all slaked lime, whether mixed with sand or not, appears to recover the whole of the carbonic acid gas previously driven off in the kiln. Hence the lime contained in old mortar is reconverted into its original chemical state of carbonate of lime. Accordingly we found, on putting a piece of old mortar into a glass of diluted muriatic acid, that the lime dissolved with effervescence, leaving the sand at bottom; and also on burning a piece of old mortar in a brisk fire for three or four hours, the lime contained in it was evidently reconverted into quick lime, for on adding water to it, it slaked in the usual manner with great heat, and fell to pieces, together with the sand which had been mixed with it, and on remixing them after this took place, they formed excellent fresh mortar, probably similar in quality to the original state in which the same had been used, more than half a century before.

(9) The sand used in making mortar should be *sharp*, that is, angular, not round, and *clean*, that is, free from all earthy matter, or other than silicious particles. Hence

Road Scrapings always, as being a mixture of sand and mud, and *Pit Sand* generally, as being scarcely ever without a proportion of clay, should be washed before they are used, which is seldom necessary in river sand, this being cleaned by the force of the current which is the cause of its formation. None but clean sharp sand will ever form good mortar, and the intimate mixture of the sand and lime, which should be done with a moderate quantity of water, is of no less importance.

I have ascertained by repeated experiments, that one cubic foot of well-burned chalk lime, fresh from the kiln, weighing 35 ℔s., as aforesaid, when well mixed with 3½ cubic feet of good river sand, and about 1⅕ cubic foot of water, produced about 3¼ cubic feet of as good mortar as this kind of lime is capable of forming.*

A smaller proportion of sand, such as 2 parts to 1 of lime, is, however, often used, which the workmen generally prefer, although it does not by any means make such good mortar, because it requires less time and labour in mixing, which saves trouble to the labourers, and it also suits the convenience of the masons and bricklayers better, being what is termed *tougher*, that is, more easily worked. If on the other hand, the sand be increased to more than the above proportion of 3½, it renders the mortar *too short*, that is, not plastic enough for use, and causes it also to be too friable, for excess of sand prevents mortar from setting into a compact adhesive mass. In short, there is a certain just proportion between these two ingredients, which produces the best mortar, which I should say *ought not to be less than* 3 *nor more than* 3½ *parts of sand to* 1 *of lime*,† that is, when common chalk lime or other pure limes are used, for different limes require different proportions.

---

* Some readers may be surprised that this mortar should occupy rather less space than the sand alone originally did, before the lime and water were added to it. The principal reason is, that dry sand, and all dry loose materials generally, settle into a much smaller space when wetted. Hence the same quantity of sand measured dry, then moist, and afterwards wet, will occupy unequal spaces. The clean sharp river sand, rather moist, used by us, weighed about 87 ℔s. per cubic foot. On gradually pouring water upon it in the measure it settled down from 12 to 9⅗ inches in height, thus occupying only four-fifths of the space, which it had before filled.

† In our first experiments alluded to in this, as well as in the 25th, and some of the following Articles, for ascertaining the best proportions of sand for making mortar with various sorts of lime, we did not try the strength of the mortars obtained, judging only, when the sand was in excess, by the apparent shortness or friability of the mixture. These experiments are therefore of little value, for we found afterwards, that weight, not measure, is the only just criterion of quantity in lime, and that the comparative quality of mortars made of various proportions of sand by measure, mixed with quick lime by weight, may be tested in a satisfactory manner, by experiments of a sufficiently simple nature, that did not at first occur to us.

When the proportion of sand to lime is stated in the above manner, which is done by Architects as a part of their specification or general directions for the execution of a building, it is always understood, when nothing is expressed to the contrary, that the parts stated are by fair level measure for the lime, and by stricken measure for the sand, and that the lime is to be measured in lumps, in the same state in which it comes from the kiln, without slaking or even breaking it into smaller pieces. It is of some importance that this shall be fully understood, because we have shown in Article 6, that quick lime from the kiln occupies when pounded a much smaller space, and when slaked into powder a much larger space, than it originally filled.

Without occasionally having recourse to actual measurements, such as the above, it is impossible to form any just estimate of the proper proportions of lime and sand for mortar; but no such measurements are usual or necessary in practice, because the expert labourer employed in this operation, on receiving general directions to use as much sand as possible without making the mortar too short, will from habit serve out the proper proportions of lime and sand with all necessary accuracy, without measuring them.

THAT THE PURE LIMES, SUCH AS CHALK LIME, &C., ARE TOLERABLY GOOD FOR DRY SITUATIONS, BUT UNFIT FOR THE PURPOSES OF HYDRAULIC ARCHITECTURE, AND EVEN FOR THE EXTERNAL JOINTS OF BUILDINGS.

(10) The pure carbonates of lime form an imperfect mortar, suitable only for dry situations, and for inside work, but not for building in damp or wet situations, in which they never *set*, as the process of induration is technically termed by workmen, but always remain in a soft pulpy state. If exposed to running water, or to the sea, as in the facing of wharf walls, &c., the lime is removed by degrees, partly dissolving and partly separating from all the external joints, leaving the sand unprotected, which is also washed away; and the destruction of the mortar will be followed by the downfal of the front of the wall, if built of bricks, or of rubble work composed of small irregular stones.

The unfitness of pure lime for the purposes of hydraulic architecture has been proved by several striking circumstances that have come under my personal observation, of which I shall only mention a few. First, a great portion of the boundary wall of Rochester Castle having been completely undermined, nearly throughout its whole thickness, which was considerable, whilst the upper part of the same wall was left standing, I had always ascribed this remarkable breach to violence, considering it as having been the act of persons intending to destroy the wall for the sake of the stone; but on examining it more accurately, after I had begun to study the subject of limes and cements, I observed that the whole of this breached part was washed by the Medway at high water, and that all the mortar of a small portion of the back part of the foot of the wall still left standing was quite soft, but that towards the ordinary high-water level it became a little harder, and that above that level it was perfectly sound.* I observed the same process at the outer wall of Cockham Wood Fort, on the left bank of the Medway below Chatham, of which the upper part was standing, whilst the lower part of it had been gradually ruined, by the action of the river at high water destroying the mortar, after which the loose bricks must have been taken away.

(11) I believe however that the above process is very tedious, and that it may require a great number of years for water to undermine a wall built of pure lime mortar. But I have ascertained that water has the same effect on the oldest mortar, if made of pure lime. For on taking a piece of the upper part of the same wall of Rochester Castle, in which the mortar was sound, and also a fragment of a substantial brick wall, within Chatham Lines, supposed to have been built in the time of the American war, and in which the mortar was also sound, and putting them both into a vessel of water near a pump, and changing the water every day for about a year, the mortar of both was dissolved out of all the external joints, and several of the stones of the former, as well as of the bricks of the latter, became unconnected, and fell to pieces.

(12) It is to be remarked, that this effect only takes place when the water is constantly changed, because the proportion of lime that can be dissolved in any given quantity of water is very small; and accordingly, after having begun to act upon a fragment of masonry by the method before described of changing the water daily, and having thus dissolved part of the mortar in the external joints, on leaving the water

---

* This breach can no longer be seen, having been repaired some years ago, when the ground outside of it, which was covered with several feet of water every tide, and by mud at low water, was also raised higher than the level of spring tides, and protected by a wharf wall, so as to form an agreeable walk for the inhabitants of Rochester.

afterwards unchanged for about six months, I found that no further effect had taken place. For as the water was saturated with as much lime as it was capable of dissolving, it lost the power of acting upon the remainder of the mortar, which therefore continued uninjured. But the water to which masonry is exposed in nature is always changing by rain or filtration, even when stagnant, so that pure lime mortar should never be used in building under water, or in marshy situations.

(13) Pure lime is so little capable of resisting the action of water, that it is unfit even for the external joints of walls exposed to the common vicissitudes of the atmosphere. For by degrees the beating rains, to which the outside of such walls is subject, will gradually destroy the mortar of all those joints to a certain depth, as may be observed by inspecting old walls built with chalk lime mortar, which have not been meddled with for some years. Hence, after a certain time, it becomes absolutely necessary to make good all those joints with fresh mortar, and this process, technically termed *pointing*, if done with the same kind of lime, must frequently be renewed, and is so troublesome and expensive that it should be avoided as much as possible, by pointing all the external joints of walls built with chalk lime mortar with cement, or with some superior kind of lime, as soon as it shall become necessary; which may not be the case until some years after the building is finished. I apprehend that it should not be done from the first, which might appear the most natural and obvious arrangement, because mortar made of chalk lime, being slower in setting, and consequently longer compressible than any other, allows the upper part of a wall to sink by degrees to rather a lower level, which effect, technically termed *settling*, although imperceptible to a common observer, is well known to persons of any experience in building, and the amount of which depends chiefly on the number of horizontal joints. Walls built with the water limes settle less, and those built with cement are entirely free from this action, because the cement used in the lower courses sets too soon for the weight of brickwork or masonry added above to make any impression on the joints. Now though the difference of settlement, even between those extremes, may be very small, it does not appear prudent to use more than one species of mortar in the same horizontal joints of a building, especially as it would give trouble to the workmen, and occasion loss of time.

(14) Pure lime mortar has sometimes been used for the backing of wharf walls, the front or facing of which has been

protected by water cement, usually to the depth of about 18 inches, or two bricks thick, from the outside of the wall. Even this system, though it does not, like the former, described in Article 10, involve the entire ruin of the wall, is highly to be reprobated. The cement protects the pure lime mortar from the direct action of water in mass, but not against wet or damp, because the moisture penetrates through the pores of the brickwork and of the cement, and although not in sufficient quantity to dissolve the pure lime mortar, it effectually prevents it from setting, so that it always remains in a state of soft pulp, and is of no more use towards the consolidation of the wall than so much moist clay.

(15) I have seen this circumstance exemplified, when part of the old wharf wall of Dover Harbour was pulled down some years ago, and also when part of the wharf wall of the old Gun Wharf at Chatham, faced with stone, but backed with brickwork, has been laid open occasionally for temporary purposes, the backing mortar in both of which was in the state of pulp. The same effect was also observable in a part of the wharf wall, as well as in a basin wall of the Dockyard at the last-named place, which were both built entirely with bricks. In those walls the front of the brickwork consolidated by cement was perfectly strong, and in one compact mass, whilst the backing mortar of the same walls was quite soft and moist; and in respect to the old wharf wall of the Dockyard in particular, when part of it was ordered to be pulled down in the winter of 1834, the workmen were obliged to blast the brickwork of the front of it towards the river with gunpowder, this part having been laid in Sheppy cement, to the thickness of 3 feet; but after having got rid of this strong facing they removed the backing by spades, which they introduced horizontally into the soft pulpy joints of the mortar, and thus turned over each course of bricks with greater ease than the operation of sod cutting in a meadow could have been performed by the same tool.

OF GYPSUM, ALABASTER, OR PLASTER-STONE.

(16) This stone, which supplies the *Plaster* for cornices, ornamental ceilings, &c., and also for the casts or models of Statuaries, is very hard, and when pure, of a handsome white colour, not unlike white marble, and in this its natural state it is usually called *Alabaster.*

It is known not to be marble, by being insoluble in diluted acids, which have no action upon it, and also from the circumstance, that when burned in the manner proper for burning lime, it will neither slake, nor will it even form plaster fit for use.

(17) The *Gypsum* fit for the purposes of building and of the Arts, is the *Granular or Massive Sulphate of Lime*, which, when analyzed, is said to contain about one-third of its whole weight of lime, rather less than one-half of its whole weight of sulphuric acid, and about one-fifth of its whole weight of water.*

To test this stone chemically, pound a small quantity of it in a mortar, and pour the powder into a Florence flask half full of distilled water, and boil it for about a quarter of an hour over a spirit lamp. Filter the turbid mixture through a paper filter, by means of a funnel, letting it drop into a glass. Pour the clear liquor into a couple of glasses, into one of which pour afterwards a few drops of the muriate or nitrate of Baryta, which is a test of sulphuric acid, and into the other a few drops of the oxalate of ammonia, which is the most delicate test of lime. Each of these will form a precipitate, the former indicating the presence of the sulphuric acid, and the latter, of the lime.

(18) The quality of gypsum may be ascertained practically, in a very satisfactory manner, by the following simple process. Pulverize a quantity of the stone, and place it in a shallow iron or tin dish, over a brisk fire, and stir it continually. In a short time, the water which was solidified in the gypsum will be driven off in steam, with so much violence that the powder will be agitated in the vessel with all the appearance of boiling. When the disengagement of steam is no longer perceptible, hold a dry warm wine glass inverted over the powder, and if the inside of it should show no appearance of moisture, you may be assured that your gypsum has been burned enough, and that the powder now called plaster is in a state fit for the use of the Plasterer or Statuary. To judge of its quality, mix a small quantity of it with water in the form of a ball, and it will set with moderate heat into a very hard fine white substance, and will even continue setting under water, but being partially soluble in that liquid in process of time, it is not applicable to the purposes of hydraulic architecture.

Another method of preparing gypsum for use is to break it into small pieces, and bake it in an oven, and afterwards grind it to powder. Both methods are used by the British Manufacturers of this article, who generally use English stone, and yet the plaster made by them is commonly termed *Plaster of Paris*, near which city gypsum abounds, and from whence it probably was first imported into this country.

---

* See Brande's 'Manual of Chemistry,' in which the proportions are stated as 26·5 of lime, 37·5 of sulphuric acid, and 17 of water. Total 81.

(19) Plaster exposed to air gradually imbibes moisture, which always injures, and in process of time entirely spoils it, for in fact it reconverts it into the same chemical state as in the original stone. Hence the powder prepared for sale is always preserved in air-tight casks or in sacks. If spoiled, it may be recovered by burning it again.

OF THE WATER LIMES OR HYDRAULIC LIMES, HOLDING AN INTERMEDIATE PLACE BETWEEN THE PURE CARBONATES OF LIME AND THE WATER CEMENTS, AND OF THE MORTARS, CONCRETE AND ARTIFICIAL STONE, THAT MAY BE FORMED WITH THEM.

(20) The *Water Limes* or *Hydraulic Limes* are composed of carbonate of lime, generally mixed with silica, and alumina, and the oxide of iron, and occasionally with traces or very small proportions of other substances. Take away the carbonate of lime from this compound, and the remaining parts are the same as the component parts of the brown or blue clays of nature. Hence these lime stones are also termed *Argillaceous Lime Stones*. They all have more or less the property of setting in watery or damp situations, and therefore they are exceedingly useful for the purposes of hydraulic architecture, and nothing can be better for the foundations and backing of wharf walls; but even these limes, when exposed to running water, are partially soluble, and therefore it is desirable to protect the external joints of wharf walls, built with mortar made of these limes, by some superior kind of water cement. For this purpose, *Puzzolana* from Italy, and *Trass* from the Rhine, usually termed *Dutch Terrace*, were formerly used. Recently, these two substances, both of which are considered of volcanic origin, have been superseded by the water cements of England, misnamed *Roman Cements*, for the purpose of mystery, or for enhancing their value, by the ingenious patentee, who first discovered their strong hydraulic properties, and introduced them into general use.

(21) The blue lias lime stones are considered the strongest water limes of this country, and are found on opposite sides of the Bristol Channel, near Watchet in Somersetshire, and Aberthaw in Glamorganshire, and also at Lyme Regis in Dorsetshire. The first of these, mixed with puzzolana, was used by Smeaton in building the Edystone Lighthouse. The Dorking or Merstham lime, and the Halling lime, so termed

from a village on the left bank of the Medway above Rochester, but which is also found near Burham on the opposite side of the same river, though not possessing such strong hydraulic properties, are also much esteemed; and these two limes, the former of which is considered rather the best, are more used in the metropolis than the blue lias, probably from the greater proximity of the quarries where they are found, and from very little land carriage being required for either.

All the water lime stones are of a bluish grey or brown colour, which is communicated to them by the oxide of iron. They are usually termed *Stone Lime* by the Builders of the Metropolis, to distinguish them from common chalk lime, but so far improperly, that the Dorking lime stone is not much harder than chalk, and the Halling lime stone is actually a chalk, and not harder than the pure chalk of the same neighbourhood, from which it is only distinguished in appearance by being a little darker.

In fact, all the coloured chalks found in various parts of England, commonly termed *Grey Chalks*, which are the *Lower Chalks* of the Geologists, and generally free from flints, are possessed of hydraulic properties more or less powerful.

(22) When a fragment of any of the water lime stones is put into a phial of the diluted muriatic or nitric acids, the whole of the carbonate of lime contained in the stone is dissolved or driven off with effervescence, so that the stone falls to pieces, leaving the silica and alumina, which are altogether insoluble in acids, together with the oxide of iron, which is also insoluble under those circumstances, as a fine muddy sediment at the bottom of the phial.

(23) Most of the water lime stones, when burned into quick lime by a heat sufficient to expel the carbonic acid gas, are of a yellowish or light brown colour, so that any calcareous stone, which after calcination assumes a kind of buff colour, may be presumed to have hydraulic properties.

All these limes slake with heat by the addition of water, and most of them also, in process of time, by exposure to air, but not so readily, nor so soon as chalk lime or other pure limes.

(24) When the water limes, after being burned into quick lime, are pounded and made up into balls with water, if one of these balls be put into a basin of water, it will expand more or less, and eventually fall to pieces; but those which contain the greatest proportion of carbonate of lime, and

which therefore approach most nearly to the pure limes, will swell to a greater size, and fall to pieces in a shorter time, than those which contain less carbonate of lime, and which consequently approach nearer to the quality of a water cement. A ball of about an inch in diameter, of the Halling lime, for example, will swell under water to twice that diameter, or to eight times its original magnitude, in about an hour and a half, after which it will fall to pieces, and if the basin used be a very small one, this process will make the water quite warm. But the blue lias lime of Lyme Regis, which approaches very nearly to a water cement, when pounded and made into a moist ball, sets very quickly, and if put into a basin of water soon afterwards, numerous cracks will probably be formed all over the surface, and eventually the ball may fall to pieces; but this effect may not take place for several days, or even weeks, after such immersion, and in the mean time it swells very little. Smeaton remarks, that the blue lias lime of Watchet slaked with so much difficulty, that when it was rather stale, the masons of that district used boiling water, which has a more powerful slaking effect than cold. If this failed, they considered their lime spoiled. In slaking any refractory lime like this, it is proper previously to break any very large lumps into smaller pieces, and to use a watering-pot, and then to follow the common practice of covering it up with sand, which, by confining the heat, expedites the process desired; but for experimental purposes, canvas is preferable to sand.

(25) We found in our first experiments at Chatham, that one cubic foot of Halling lime weighed rather more when fresh from the kiln, and by the gradual addition of water that it dilated nearly to the same increased bulk in the state of slaked-lime powder, but when worked up into mortar not too short for use, that it would not bear quite so large a proportion of sand as the common chalk lime had done. This experiment leading to a result in opposition to a common opinion amongst the Builders of the Metropolis, which is that the Dorking and Halling limes, as being stronger limes, will, when made into mortar, bear more sand than common chalk lime; I was induced to examine the principle upon which they found this opinion, which, on consideration, appears to me to be erroneous; because these two limes, and all the other hydraulic limes, are undoubtedly in an intermediate state between pure lime, which is the weakest, and the water cements, which are the strongest, of all calcareous cements: and every one will acknowledge that the proportion of sand,

which will make good mortar with chalk lime, would entirely ruin cement, which can scarcely bear more than one-third of that quantity. Hence it follows, that the hydraulic limes ought not to admit of so much sand as chalk, but that they will bear more than cement, without being injured.

Accordingly I conceive that *three cubic feet of sand to one of Dorking or of Halling lime, will be a good proportion for making mortar with those limes,* which approach very nearly to pure lime.

(26) But *the blue Lias Lime will not make good mortar if mixed with more than two cubic feet of sand to one of lime.* This opinion, first formed by me from analogy, and in consideration of the blue lias approaching very nearly to a water cement, proved on due inquiry to be borne out by, and exactly conformable to, the practice of the masons of Lyme Regis. But Captain Savage, of the Royal Engineers, who was employed professionally some years ago in improving the *Cobb* or Pier of that little Seaport, which was done by tide-work, and in which no other kind of lime was used, assured me that he found that a smaller proportion of sand than 2 to 1 made still better mortar. We have since ascertained by repeated experiments at Chatham, that 1 cubic foot of blue lias lime from the kiln, weighing 47 ℔s., mixed with 2 cubic feet of sand, made mortar fit for use, but which could not have borne more sand without becoming too short.* We found also that blue lias lime from the kiln, like all the other limes that we experimented upon, filled less than its original measure, when reduced by pounding to the state of quick-lime powder; but when slaked, it only dilated into one cubic foot and a third of slaked-lime powder, not including about one-eighteenth part of a cubic foot of core, which we threw away. Hence it expands less by slaking than either chalk lime or Halling lime.

---

* Having ascertained by the usual test of the diluted muriatic acid (6), that the blue lias lime used in our first experiment was sufficiently burned, we tried a piece of it with cold water, which produced very little effect; and then another piece with boiling water, which slaked it almost immediately. Being aware, therefore, of the difficulty with which it slakes in cold water, we caused the cubic foot of blue lias lime used in this experiment to be previously pounded, but not very finely, in order to facilitate this process, notwithstanding which it still slaked very slowly, rendering this experiment much more tedious than any of our former ones. I have since ascertained from Captain Savage, that the difficulty must have arisen from our not having allowed sufficient time; for he assures me that blue lias lime made up into a heap, and treated as described at the end of Article 24, will always slake properly with cold water, if allowed to remain covered up for 18 hours.

OF CONCRETE, AND ARTIFICIAL STONE.

(27) One of the most important uses of the water limes is in the formation of *Concrete* for foundations, &c., which, if judiciously applied, supersedes the very expensive, troublesome, and precarious process of piling and planking, even in the softest soils.* This is a recent improvement, first adopted by Sir Robert Smirke with success, in the foundation of the Penitentiary at Millbank, where the soil, consisting chiefly of peat moss, was soft to a very great depth.† His example has since been followed by other Architects, as well as by Civil Engineers and Builders, who have used concrete not only like him for foundations, but for the backing of wharf walls and docks, and more recently for entire walls and buildings.

(28) Concrete is formed by mixing lime, coarse gravel,

---

* A piled foundation is peculiarly precarious, not only from the neglect or fraud of the persons employed, to which, from their work being buried, and from the value of wood, there is more than usual temptation; but even when perfectly well executed, from sometimes losing its perpendicularity in very soft soil, and from its being liable to rot in process of time, in all situations, excepting those which are constantly under water.

† In excavating for one of the piers of Waterloo bridge, the workmen had a good deal of difficulty, owing to the very compact state of the gravel forming the bed of the river, which every where else they had found perfectly loose. This effect had been produced by the accidental sinking of a barge load of lime over that spot some time before, which had cemented the loose gravel into a solid mass, resembling the calcareous conglomerates of nature, which are gradually formed by a similar process. Mr. Rennie having mentioned this circumstance to Sir Robert (then Mr.) Smirke, the latter, with great judgment, availed himself of the hint, and subsequently used it in all his foundations, none of which have ever been known to fail. Part of the Penitentiary at Millbank, begun by another Architect in a different manner, before Sir Robert Smirke was employed there, was evidently giving way. The superior efficiency of concrete was also proved in a remarkable manner at the new Custom House, where the floor of the large apartment called the long room actually fell in, and the whole building was in danger, owing to the insufficient manner in which the piling had been originally executed in a very difficult situation. At this period Sir Robert Smirke was consulted, who found it necessary to pull down a small part of the building, but saved the rest of it by undersetting all the walls with concrete, to the average width of 12 feet, and to the depth of from 12 to 15 feet, that is, until he found a natural bed of gravel, including one course of Yorkshire landing stones, and twelve courses of bricks laid in cement, having three or four offsets or footings between the Yorkshire landings resting on the concrete, and the base of the original walls. No other expedient could possibly have saved this fine edifice from entire demolition. It must be allowed, that not only the ancient Romans, and after them the Moors, but even the Norman Barons of England in their feudal castles, used concrete, of which Kendal Castle is one of the most striking examples; and more recently, Belidor, in his 'Architecture Hydraulique,' treats of Beton mortar, which is much the same; so that it is not absolutely new. In fact, according to the old proverb, there is scarcely any thing new under the sun; but the merit of introducing this immense improvement systematically and generally into the modern practice of Architecture, is undoubtedly due to Sir Robert Smirke.

and sand together, with a moderate quantity of water, which is usually done on a large square board, having a margin raised a little above it on three sides only. The lime used for this purpose has usually been reduced to fine powder by pounding or grinding it, whilst fresh from the kiln; and it has generally been considered of so much importance not to slake it until ready for use, that it has been customary to mix it with the gravel and sand in a dry state for a little while, before the water was added; after which the whole of these ingredients have been intimately mixed, with as much expedition as possible, by employing two labourers to work together at each of the mixing boards, which being always placed as near to the spot previously prepared for the foundation as possible, the concrete is either thrown down at once, or wheeled a little way, and dropped from a temporary scaffold with moveable planks, which is usually necessary, into the excavation, where it is spread and levelled, and trodden down, or sometimes rammed by other labourers below. It is considered useful to throw it from a height, as each shovelful or barrowful compresses the mass already below by falling upon it. Concrete is sometimes only laid in trenches cut for the foundations of the several walls of the building, and of such a width as to enable it to occupy a much larger base than the walls themselves, without which it would be of little or no use; but in the foundations of more important edifices, especially if the soil be very soft, it is more usually spread over and somewhat beyond the whole area on every side, in successive layers of about a foot in thickness. The most experienced Builders are of opinion, that its depth should never be less than 4½ feet, and that it need seldom exceed 6 or 7 feet under ordinary circumstances.* Concrete made in this manner, according to the system first introduced by Sir Robert Smirke, throws out a moderate heat on the slaking of the lime, and soon begins to set, forming in time a kind of artificial rock, supporting the whole weight of the walls of a great building, upon so large a base, as to prevent those unequal settlements of the various parts, in proportion to their unequal weights, which first cause unseemly cracks in the walls, and in time the ruin of the building. As soon as a foundation of this kind is finished, the heaviest building may immediately be commenced upon it, and however quickly the walls may be carried up, the concrete will have set sufficiently to bear their whole weight, for no failure has ever occurred in thus using it, although I am inclined to believe that many years may elapse before the great masses of concrete, buried in such foundations as those of the Penitentiary, which extend beyond the whole area of the building, and are said to be 12 feet deep, can attain their maximum of induration.

---

* But if a solid stratum, whether horizontal or inclined, can be found by excavating somewhat deeper, the thickness of the concrete should be increased, so as every where to rest upon it.

(29) When concrete, which was only used for foundations by Sir Robert Smirke, was afterwards applied to the formation of walls, of which the Sea wall, East Cliff, Brighton, built with concrete prepared in a different manner, at the suggestion of Mr. Thomas Cooper, Architect and Builder, of that town, affords the first and most remarkable example, it became necessary to use a mould or hollow wooden profile suited to the proposed form of the wall, into which the mixture was thrown and allowed to set. The simplest mode of accomplishing this object, is that which has been long used in Spain, and in part of the South of France, for constructing houses, frequently of more than one story high, with rammed earth, which is called *Tapia* in the former, and *Pisé* in the latter country. Two sets of boards are ledged together, each set forming an oblong of any convenient length, but of moderate height, which are connected near the top and bottom by iron bolts, to keep them at their proper interval apart. After the foundation is finished by cutting a trench, and throwing concrete into it in the usual manner, the mould thus formed is placed upon it, on the same level as the natural ground, and filled with concrete, and when that has set sufficiently, it is moved to another situation, which may be done by drawing out the iron bolts, after unscrewing the nuts by which they are confined; and thus the whole of the first course of concrete, of a height corresponding to that of the mould, is finished over the whole base of the wall or walls. The moulds, for more than one would be necessary, are then put together on a higher level, and another course of concrete is formed by the same process, and so on, until the whole height of walling necessary is completed in regular courses, upon each of which the moulds rest successively as the work rises.*

In the Sea wall at Brighton, boarding was used in the front only, because the back of the wall either rested on the natural chalk cliff, or was made good with chalk rubbish, which superseded the use of woodwork on that side. The concrete used in this wall was formed of a mixture of grey chalk lime obtained from a distance, with the coarse shingle and sand found on the beach at the foot of the cliff; for the base of this wall is every where above the level of high water, except in a small portion of its length, where the lower part of it has very judiciously been protected against the action of the Sea, by permanent woodwork fixed in front of it.*

---

* The extraction of the iron bolts, after the mould is removed, leaves holes extending entirely through the concrete. In fixing the mould on a higher level, the lower bolts are passed through the same holes, from which the upper bolts were previously taken out.

(30) Afterwards Mr. Ranger extended the same process to the formation of artificial stone, for which he took out a patent, and which for some purposes may be considered a great improvement, although it only differs from the concrete first used, in being mixed with boiling water instead of cold, and in being formed in moulds of moderate size, instead of great masses. Numerous examples of this mode of building may now be seen, of which two houses (Nos. 16 and 17) on the north side of Pall Mall, the College of Surgeons, Lincoln's Inn Fields, the porticos of Wellington Barracks and the Guardhouse in the Birdcage Walk, St. James's Park, are the most convenient for inspection of any in the metropolis.

The moulds used by Mr. Ranger in forming his artificial stone, have a flat board for the bottom, which is somewhat larger than the base of the proposed stone. The short upright sides of the mould are fitted in close between the two other upright sides, whose ends project a little way beyond the former, and are then secured by iron cramps, which being properly wedged up, keep all tight. A couple of oak trenails pass through both sides of the mould towards the ends. A number of these moulds being laid out in a line, the mixing boards are placed near them, in which the sifted quick-lime powder and the proper proportion of gravel and sand are mixed with boiling water, with all expedition; and the mixture is thrown immediately into one of the moulds, in which it is continually rammed, until the mould is quite full, when a smooth surface is made upon the top of the artificial stone afterwards by a plasterer with his float, with fine mortar of the same kind of lime; and this may be done also on any other of the sides of the stone, that may require it, that is, on such as are to appear in the face of a wall. Mr. Ranger has not only formed his artificial stones of moderate size, like common building stones, but has made very large massy blocks for ornamental cornices, in which the mouldings have been finished by the plasterer, after the mass of each block has been cast in the mould. The use of boiling water causes the lime to slake much more rapidly and with greater heat than cold water would do (24), and is so far an advantage, that it enables the men to work with fewer moulds in making artificial stones; but as my own experiments have not convinced me, that rapidity of slaking or setting either makes cement or mortar of the same quality better eventually, than if allowed to slake or set more slowly, I do not see that there can be sufficient advantage to compensate the expense of boiling the water, and even heating the gravel, which I have known Mr. Ranger also do. When the artificial stones made in this manner have set sufficiently, for which about half an hour is considered a reasonable time in working with Halling lime, the moulds are taken to pieces, first drawing out the trenails, which leaves a couple of cylindrical holes in each of the artificial stones, for the purpose of afterwards hoisting them up to their proper position on a wall, without injuring them. The wedges are then knocked out and the cramps disengaged, which allows the upright sides of each mould to be removed, after which the artificial stones are disengaged from the bottom boards of their respective moulds and laid on skids to dry, until they set more thoroughly, and after the experience of some years, it is now considered desirable that they should remain two or three months in this state, before they are used.

---

* The Sea wall at Brighton, planned by Mr. Cooper as above mentioned, was intended to be every where 2 feet 6 inches thick at top, with a slope of one-third, and the foreman assured me that in one part it would be no less than 60 feet high, so that its thickness at the base there would be 22 feet 6 inches. Its height varied, being much less in other parts. The boarding used on one side only was 20 feet long, and 4 feet 9 inches high. This wall was built under the direction of Mr. John Wright by Mr. Wm. Lambert, both afterwards employed on the South Eastern Railway, the former as resident engineer, the latter as contractor, where they constructed a wall of the same description, but more substantial, being 4 feet thick at top, to retain an embankment on the beach, over which the railway now passes.

(31) Sir Robert Smirke informed me some years ago, he himself being then the only person who had made use of concrete to any extent, that he would not scruple to erect the heaviest Dock for shipbuilding upon a concrete foundation, instead of the very expensive, but certainly excellent, foundations of piles and other woodwork, and of bricks laid in cement, which had been at that time used for the fine new granite Docks at Sheerness and Chatham, built by the celebrated Mr. Rennie. At that time I believe no one contemplated the still bolder measure, since adopted by Mr. Taylor, the present Architect of the Admiralty, who gave in a plan a few years ago for building Docks of the largest size,

and also wharf walls, both at Woolwich and Chatham, entirely with Mr. Ranger's concrete and artificial stone, which, having been approved by the Lords Commissioners of the Admiralty, was ordered to be carried into effect. From the numerous experiments which I had previously tried on limes and cements, it was my opinion at the time, that these Docks and Wharfs, after being finished, would gradually give way at the surface, unless protected against the action of water in mass, as well as against those collisions to which such walls are liable, by a facing of stone or of brickwork laid in cement. This arrangement has subsequently been adopted by Mr. Taylor himself for these Docks, which have been faced with granite, but not for the wharf walls, where the facings of artificial stone still remain exposed to every high tide, and where time will show whether my apprehensions of its insufficiency are well founded or not.*

(32) Upon the whole, it may be allowed that the use of concrete and artificial stone, if kept within proper bounds, that is, so as not to attempt to supersede stone and brickwork entirely, is a very great improvement. When I first saw the Sea wall of Brighton in progress some years ago, I could not help being struck by the facility which the like application of concrete would afford for fortifying sandy islands, where neither stone nor earth fit for brickmaking are to be found, and which are often important military posts. Adopting this arrangement, it would not be necessary to import any thing but quick lime in barrels or sacks for building the scarp and counterscarp revetments, and even for casemates, as was proved in May, 1835, at Woolwich, by an experiment tried by order of the Master-General of the Board of Ordnance, at the suggestion of Lieut.-Colonel Fanshawe, of the Royal Engineers, who proposed that a vault of 18 feet span, 5 feet rise, and 4 feet thick at the haunches, being of the dimensions suitable for a military casemate,† should be built with

---

* Let it be fully understood, that my opinion was only expressed to private friends, but neither made known to the public nor to any official person. In fact, I was particularly glad that the experiment of concrete docks and wharfs was tried by Mr. Taylor, which I considered at the time not only a very bold, but so far a safe one, inasmuch as I had not the smallest doubt of the efficiency of this substance for the great mass of the work; and if it should fail in the external surface, it appeared to me that this part of the concrete might be cut away, and a facing of granite added and bonded into it, without difficulty and with very little more expense than if this arrangement had been adopted from the first. I believe that the chief difficulties attending the execution of the concrete Docks at Woolwich and Chatham were in some measure independent of the material used, owing to land springs, &c.

† The vault was 18 feet long and 6 feet thick immediately over the crown of the arch, where it was formed with a ridge, in the usual manner. The piers

Mr. Ranger's concrete, on the marsh adjoining to the Arsenal at that place, and exposed to the fire of heavy mortars and guns, which was done in little more than two months after it was finished; and, contrary to previous expectation, it was less injured by the vertical fire of 13-inch shells, each loaded so as to weigh 200 lbs., than by the direct fire of 24-pound shot. Notwithstanding this favourable result, I would recommend brickwork laid in cement always to be used for casemates, where it can be had, in preference to concrete, for the former not only sets immediately, but if afterwards covered with a coating of net cement, brick casemates afford a dry wholesome shelter for troops, whereas the concrete would always be damp.

(33) One peculiar advantage of Mr. Ranger's artificial stones is the greater conveniency of applying concrete to the walls of a common building in this form than in mass; but it appears to me that they also possess another advantage, less obvious but not less important. If laid out for two or three months before they are used, the great surface which these stones present to the air, combined with their small bulk, enables them to set much more thoroughly than an equal quantity of concrete in mass could possibly do in the same time, for I believe that the induration not only of mortars and concrete, but even of cement, is gradual, taking place first at the surface, and from thence proceeding regularly towards the centre.*

---

which supported it were 8 feet wide and about 4½ feet high to the spring of the arch, with foundations 10 feet wide, having an offset of 1 foot on each side. It was commenced in the beginning of February and finished the 17th of March, 1835, and the centres struck four days afterwards. The piers were built in successive courses of about 1 foot thick, and the arch was begun from both sides, in the form of voussoirs extending its whole length, the eleventh of which completed it by forming the key stone.

* In the experimental casemate at Woolwich, mentioned in the preceding Article, the concrete at the surface was every where quite hard, but several smooth cylindrical holes, about 6 inches in diameter, formed in one of the piers or side walls to the depth of about 3½ feet, by the penetration of the 24-pound shot fired into it, afforded me an opportunity of observing that the lime, not only at that depth but even much nearer to the surface, was quite soft and moist. The 24-pound shot shattered the hard surface first, producing a breach resembling the crater of a small mine 2 or 3 feet in diameter, and about a foot deep, beyond which, in continuation of their course, they bored the regular cylindrical holes before mentioned. The 13-inch shells did not penetrate much more than 1 foot into the top of the arch, producing holes, nearly an impression of their own form, without shattering the concrete much, but by their concussion they also produced some fine cracks in the arch. This, however, had been previously injured by the unequal settlement of the piers, one of which had sunk nearly a foot, and the other about 4 inches less, in the very soft marshy soil on which they had been founded, the nature of which may be understood from the circumstance that the 13-inch shells, which happened to miss the casemate, sank 15 or 16 feet below the surface.

(34) Neither gravel without sand, nor sand without gravel, can form good concrete. The large pebbles composing the former, if mixed with quick-lime powder and water, would only be cemented together by lime paste, or as it is technically termed, *Lime Putty*, filling up the large interstices between them, which is known to be the weakest form of lime. On the other hand, fine sand alone would produce nothing better than a mass of common mortar, which has very little strength in itself, but is excellent for cementing larger materials. The proportions of the gravel and sand used are of little importance, provided that the former be rather large, and the sand sufficient to fill up the interstices in it, for which purpose a mixture of coarse and of fine sand is better than one sort only. But no such mixtures are necessary, in using the sandy gravel of many parts of the Thames, where it is found in the state most suitable for making good concrete, and is employed both for this purpose, and as ballast for shipping.

(35) It being known that clean gravel and sand, when put dry into any measure, will almost immediately settle to a lower level on the addition of a certain quantity of water, and it being a matter easily proved that no ramming can possibly compress them afterwards, it appears to me, that the proportion of lime used in concrete should be just sufficient to combine with the gravel and sand in this compact state; that is, after the violent action of slaking shall have subsided,* which causes a temporary expansion, that is counteracted whilst in operation, by the usual process of treading down or ramming concrete.

(36) In their specifications for concrete foundations, it

---

* Formerly great importance was attached not only to the proper incorporation or mixture of all the ingredients, but also to the continual beating of mortar, which was carried to such an extent that Smeaton reckons it a fair day's work of a labourer, to mix and beat up 2 bushels of quick-lime powder with 1 bushel of Dutch Tarras, vulgarly termed Terrace, which probably would not make more than 1¼ cubic foot of mortar. This practice was not only recommended by him, but by Dr. Higgins, who also investigated the subject of calcareous cements with great industry and sagacity. In the present day, the beating of mortar has become obsolete, at least I have never seen it used in any of the great works which I have inspected whilst in progress in or near the metropolis, for many years past; and with great respect for the opinion of those two able men, I doubt much whether the advantages were sufficient to counterbalance the extra labour involved in this troublesome and very tedious process. The most esteemed mortar now is that made by the pugmill, which mixes it extremely well and compresses it also, as it forces out the ingredients, which enter at the top of the mill, through a small hole at the bottom of it; and this is done so expeditiously, that the quantity of mortar, which might be a day's work of a labourer, according to the beating system of Smeaton and Higgins, would be mixed in two or three minutes by the pugmill.

is usual for Architects to direct that it shall be made by mixing so many parts, usually not less than 6 nor more than 8 of gravel and sand, with 1 part of ground or pounded and sifted quick lime;* but it was before stated, in Articles 6, 24, and 25, that quick-lime powder occupies less space than the same quantity of lime does when received from the kiln. Hence the above two proportions, if stated as usually done in the specifications of the same Architects for making mortar, would only be equivalent, the first to 4 measures of gravel and sand, mixed with 1 measure of lime from the kiln, and the second to 5½ measures of gravel and sand, mixed with 1 measure of lime from the kiln; but even when thus explained and corrected, the same quantity of lime is mixed with so much more silicious matter in making concrete than in common mortar, that when both are good of their kind, it might be supposed on a hasty view of the subject, that the same lime had a more powerful cementing action in concrete than in mortar. This, however, is not the case. When the ingredients for making concrete are mixed together, the lime combines with the fine sand only, forming a mortar which cements the large gravel and coarser sand together, in the same manner in which the like mixture of fine lime and sand, previously made up into mortar, cements the stones of rubble masonry built of small materials. Hence, in reality, the lime used in concrete does not combine efficiently with more sand than it does in mortar; and its cementing properties and power in both are precisely alike.

(37) For example, in the concrete used in the Sea wall at Brighton before mentioned, six parts of large shingle and sifted sand were mixed with one part of grey chalk lime from the kiln. But in making it, the ingredients were not all mixed together at once, according to the usual custom. Three parts of sifted sand and one part of lime were actually made into mortar by labourers first, after which this mortar and the coarse beach shingle were thrown, in equal quantities, namely, by one barrowful of each at a time, into a pugmill worked by a horse, which in mixing them into concrete produced a more intimate union of all the ingredients, than could have been effected by manual labour, it being well known to practical men, that no common workman will ever mix mortar so well or so quickly, as can be done by

---

* In grinding quick lime, the underburned parts of the core are retained, which are rejected as prejudicial in making mortar. But when previously reduced to fine powder, as in making concrete, a little core can do no harm.

this very useful and simple machine. The concrete of the Sea wall of Brighton was therefore formed with lime previously slaked, on the same principle as in making common mortar, instead of working with quick lime, according to the system used by Sir Robert Smirke, and refined upon by Mr. Ranger.*

(38) But whatever proportion of the ingredients may be stated by an Architect in his specification, the same practice prevails in making concrete, as in mortar (9). No precise measurement ever takes place, the matter being left to the sagacity of the labourers employed, who produce mixtures of uniform quality with extraordinary accuracy. Those in the employment of Mr. Ranger, in working with Halling lime, make up one barrowful of sandy gravel into concrete at a time, which they mix with two small shovelfuls of sifted quick-lime powder, the proportion being apparently about 8 measures of the former to 1 of the latter, in combining which they use a small pailful of boiling water.

(39) It may be observed, that as different limes require different proportions of sand in making mortar, from the circumstance that those which have the most powerful hydraulic properties are not capable of combining with so much sand as common lime, it follows that different limes must also be used in different proportions in making concrete. For this reason, if it were attempted to make concrete, or to make artificial stone, with the same proportion of gravel and sand and of blue lias lime, which is the most suitable in working with Halling lime, I conceive that the concrete thus formed would be much too friable. It is essential that this should be understood, lest the best lime should lose its character by being injudiciously used.

GROUTING DEFINED. IN WHAT RESPECT IT DIFFERS FROM CONCRETE. ITS GREAT UTILITY.

(40) When a thick wall of rubble masonry, chiefly of small and irregular materials, is built in successive courses, with all the stones at first laid dry, excepting the outside ones of each course, or when long irregular stones in the form of an arch are laid dry over a wooden centering, and

---

* It appears worth while to record this difference, because in working with limes that slake easily, such as the Dorking and Halling limes, if the concrete formed both ways should be equally good in the end, it may be convenient to dispense with grinding them.

N.B. Such was my original note, written in doubt as to the necessity of using quick lime. Subsequent experiments have convinced me that it is of no use in concrete for foundations, but that in making artificial stones, it is a positive disadvantage.

quick lime slaked with excess of water, either with or without sand, is poured in a liquid state, into the mass of dry materials composing every such course or arch, the work is said to be *grouted;* and this process, which is of great antiquity, is so analogous to the mode of forming concrete foundations above described, that these were often called grouted foundations, when first introduced. It is proper however to make a distinction between the terms *Grout* and *Concrete,* because the best Architects are now in the habit of causing brick walls to be grouted, in a manner which from the uniform dimensions of bricks, and the extreme regularity with which they are laid, has no resemblance either to the ancient grouting or modern concrete. This is done sometimes in every course, sometimes in every third or fourth course only, of a brick building. A bed of mortar being laid on the uppermost course of the finished part of the wall, and the outside bricks only being placed, so as to leave a kind of channel in the middle, water is thrown upon the wall, and the mortar and water are mixed together by raking backwards and forwards with a kind of long-handled iron hoe called *a Larry,* which converts the mortar into grout, making it so liquid that it runs down into all the vertical joints of the course below it, and completely fills them.* This system of grouting is very judicious, because it prevents any of those joints from being left wholly or partially dry, which is too often done by bricklayers working in haste, and which, if not observed at the time, cannot be detected afterwards, without pulling down a part of the wall. Indeed, it requires great attention, even for a very good bricklayer, to fill, or as it is technically termed, *to flush* all his vertical joints with common mortar alone;† but no part of these joints can escape from the grout or liquid mortar, which penetrates into every crevice. This system was followed by Sir Robert Smirke in building the new British Museum, in which every course of the brickwork was grouted, wherever the walls were two bricks and a half thick or upwards, but in the thinner walls of the same building, which however are comparatively few in number, every third or fourth course only was grouted.

---

* This must be done in thin walls by pouring the grout out of pails.

† Any person, who has examined old brick buildings, whilst being pulled down, must have observed, how many of the vertical joints are entirely or partially dry. I believe that this has often been the cause of disastrous fires. I once knew a skirting board in a room in the basement story in Brompton Barracks, Chatham, having been set on fire from this cause, in consequence of a barrack serjeant's family in the next house having made a small oven on the other side of the same party wall.

Upon this subject, I may be permitted to remark, that unless every course be grouted, it appears to me that there is a risk of the grouting not penetrating lower than the single course immediately under it, for the beds of plastic mortar in the next courses below that, have sufficient consistency to intercept the grouting, unless those beds themselves should have been imperfectly laid, which seldom or never happens, even when middling or indifferent bricklayers are employed. For this reason, one can scarcely expect sound brickwork, unless every course be grouted, especially in thick walls, although the more general custom is to work with mortar only. When one of the massy walls of the new British Museum, after being grouted in the manner before described, was cut through for some temporary purpose, it was remarked that the brickwork resisted the tools of the workmen quite as much, and appeared equally firm in the joints, as if the latter had been filled with plastic mortar instead of grouting.* The same risk of part of the vertical joints being left dry may occur also in masonry, and there can be no method of guarding against it more effectual than to grout each course.

OF MAGNESIAN LIME STONES.

(41) There are no magnesian lime stones, that I am aware of, in the South of England. The small specimens that I have been able to procure appear to me to possess hydraulic properties, and I hear that such is their character in those parts of the North of England where they abound; but as all those specimens were coloured, generally with a yellowish tint, and only partially soluble in the diluted acids, it follows that they must have some additional ingredient in their composition, besides the carbonates of lime and of magnesia, the latter of which when pure is also white, and entirely soluble in acids like the former, but with less effervescence.

OF THE WATER CEMENTS OF ENGLAND, ABSURDLY TERMED ROMAN CEMENTS, AND OF THE MODE OF TESTING THEM, AND OTHER NATURAL CEMENT STONES. THEIR PECULIAR PROPERTIES AND ADVANTAGES. THAT IT IS NOT EXPEDIENT TO USE THEM FOR CONCRETE.

(42) The term *Water Cement* holds good in a double sense, implying not only one which sets under water, but one which, being of a calcareous nature, is prepared for use by mixing it with water.†

---

* This circumstance is an argument against the necessity of beating mortar, according to the system formerly in repute. (See the Note to Article 35.)

† In contradistinction to *Oleaginous Cements*, such as *Mastich*, which is a

The best water cements of England are the Sheppy and the Harwich cement, which are most used about London, and the Yorkshire cement is also said to be good, but of this I speak from report chiefly. They should always be designated in this manner by the places from whence they have been obtained, and not by the absurd title of Roman Cement, which serves only to mislead the ignorant, and being used alike for each, and all, and for every mixture of those cements, prevents those who are better informed from knowing what sort of cement any manufacturer of that article is offering for sale, unless they make minute inquiries, or personal observations, at his cement kilns.

These cements differ chemically from the water limes, only in containing a smaller proportion of carbonate of lime, and a larger proportion of silica and alumina in their composition, than the latter. Practically they differ from lime in several remarkable particulars.

First. The water cements will not slake at all, after being burned, boiling water having very little action upon them, and cold water none at all,* unless they be previously pulverized, by pounding or grinding them, which is therefore always done in preparing them for use.

Secondly. The fine calcined powder thus obtained, when made up into a ball with water, does not swell or go to pieces, whether in air or if put immediately afterwards into a basin of water, but sets or hardens without any perceptible alteration of its bulk, under water, in an infinitely shorter time than the best limes do in air. The first of those properties was no doubt the cause which prevented men in this country from discovering the nature and use of the cement stones on the South-East coast of England, until within the

---

mixture of litharge, stone-dust and linseed oil, and to *Resinous Cements*, such as the *Mineral Fusible Cement*, proposed by Mr. Fitz-Lowitz, and experimented upon by Lieutenant-Colonel Sir J. M. Frederick (then Captain) Smith, of the Royal Engineers, in 1829, who reported that when prepared for use by melting it in a caldron over a fire, and mixing it with twice its own weight of sand, it appeared stronger than the Sheppy or Harwich Cements, though the latter was used net. But it was then about 50 per cent. dearer than the natural cements, and in most situations its inflammability would be a strong objection against the use of it, for I found that it would burn even in the flame of a candle.

* I have found by repeated experiments, that when cement from the kiln is sprinkled with boiling water, the pieces usually crack or split, and much more heat is produced than is due to the temperature of the water, so that all the symptoms of incipient slaking are observable; but this process seems suddenly to stop short, for the cement does not fall down into a fine powder, and thus the heat goes off without the fragments losing their solid form, at least within the space of two days, after which period, not anticipating any further change, I have always thrown them away.

last forty years, when the light of Chemistry began to be more generally applied to the practical arts.* The second property is that which renders them particularly valuable, under situations and in circumstances where the best limes would fail.†

Thirdly. Cement is always weakened by the addition of sand, whereas every kind of lime is improved by it, so that in all cases lime mortar made with the proper proportion of sand, is much stronger than lime putty.

Fourthly. When cement powder, whether net or with the addition of sand, is mixed with water, for the purposes of Practical Architecture, it must always be used before it becomes warm, after which process it must never be disturbed, so that any portion of it that could not be used immediately must be thrown away; whereas mortars made of all limes, and more especially of the pure limes, may be disturbed, and if not used immediately, they may even be remixed by adding more water, without materially injuring them.‡

(43) To analyze a cement stone or any other compound mineral accurately, so as to obtain the precise proportional

---

* The properties of the Sheppy cement were first discovered by Mr. Parker, who took out a patent for the sale of it under the title of Roman Cement, but which from him as the discoverer, was at first often termed Parker's Cement. Afterwards Mr. Frost, whose more recent labours I have noticed in Article 6, discovered that the stone on the beach near Harwich, belonging to the Ordnance Department, had similar properties. The Yorkshire cement is sometimes termed Atkinson's Cement, from the name of the Architect who introduced it in London, or Mulgrave Cement, from the Earl of Mulgrave. It appears to me that the names of all water cements should be derived from the localities where they are obtained, which is always done in respect to limes. The use of such cements, a recent discovery first made in this country, was entirely unknown, not only to the Romans, but to all other nations, until Mr. Parker's time.

† A joint of brickwork laid in net cement becomes harder in half an hour, than the best mortar made of Dorking or Halling lime would be in six months or even more. Recently, on inspecting a fine brick building in Southwark, now ready for receiving the roof, I observed that all the joints of the vaults and of the flat arches over windows, which were laid in cement mixed with sand in equal parts, were perfectly hard, resisting the edge of a shilling, whilst the joints of the mortar, which was no less good of its kind, being made of the best Halling lime mixed with clean river sand, were so soft, even in the lowest and first finished parts of the walls, that the edge of a shilling raked out any part of them with almost as much ease as if they had been composed of sand alone.

‡ Notwithstanding this distinction between cement and limes, the properties of all calcareous stones appear to me to be so analogous, that I cannot help thinking that it is possible, that cement mixed with a moderate quantity of sand, and made up with water into a heap, and left for some hours, or even for some days, might bear remixing, and that in process of time it might even set, like a heap of remixed lime mortar. But as the chief or only advantage of cement over such limes as the blue lias or Aberthaw is its instantaneous setting, and as I conceive that remixed cement will probably set, if at all, more slowly than lime mortar, the rule never to disturb cement that has been used, and never to use cement that has been long mixed, should always hold good in practice.

weight of each of its component parts, is not only one of the most difficult operations of practical Chemistry, but demands much more time than Architects, Engineers, or Builders in full employment, can spare. I beg, therefore, to suggest the following simple and satisfactory mode of proceeding in testing a stone supposed to be a water cement, which ought of course to be of a bluish grey, or brown, or of some darkish colour, as white indicates pure lime stone or gypsum.

From their containing silica and alumina, which are the component parts of clay, the natural cement stones, on being touched by the tongue, indicate sensibly the presence of clay, which is also detected by the smell after wetting them. They only dissolve partially in diluted acids, leaving a more copious sediment than any of the lime stones.

(44) The first test, therefore, is to pour a little diluted muriatic or nitric acid into a wine glass, and drop a fragment of the stone into it. If no action take place, it is neither a lime stone nor a cement, but if it effervesce and fall to pieces with a muddy sediment, it is probably a water cement.

(45) To ascertain this point, break the stone, if necessary, into compact fragments not exceeding one inch and a half in thickness, and put two or three of these into a common fireplace, first heating them gradually, that they may not burst into too many small pieces, and keep them exposed to a full red heat for about three hours.

At the end of this time, take one of your specimens out of the fire, and put a small fragment of it into a glass of diluted muriatic or nitric acid. When the stone is burned enough, that is, when all the carbonic acid gas has been driven off by the heat, no effervescence will take place in the acid. A moderate effervescence will show that it is a little underburned, but violent effervescence will show that it is very imperfectly burned, and it should therefore be put into the fire again.

At the same time great care must be taken not to overburn the cement, which is always injured, if not entirely spoiled, by excess of heat. When moderately overburned its colour is changed to a much darker tint than ought to belong to it, which may easily be judged of after a few trials, and which is a proof of incipient vitrification; for by excess of heat all the natural cement stones may be fused into a dark-coloured glassy substance, resembling the volcanic product called Obsidian.

If, therefore, the calcined cement stone do not effervesce with acids, and if at the same time its proper colour be not changed to a darker one on taking it out of the fire, these circumstances prove that it is properly burned.

(46) In this case, you must take your specimens and pound them in a mortar, until they are reduced to the state of impalpable powder. To ascertain whether the calcined cement be sufficiently pounded, take a pinch of it between your finger and thumb, and rub it backwards and forwards. If it feel gritty to the touch, so that after having rubbed away the finer parts a number of small solid particles remain, let the whole of the powder be pounded finer, until on repeating the same process, no such grittiness is perceptible, and no such particles remain. This is of the greatest importance, for I have ascertained that the best cements, both natural and artificial, are very much deteriorated, if imperfectly ground or pounded after calcination.

(47) The next process is to take a small quantity of the fine powder, and mix it up with a moderate quantity of water by means of a spatula or strong knife, upon a slate or porcelain slab, and knead it into the form of a ball by turning it between the palms of the hands. It will then soon become warm, and if it be a good water cement, it will not only set or harden in the heating, but if put into a basin of water, it will continue hard, and even become harder in the basin. A ball of good cement will set under water, even if put in quite soft and before it becomes warm; and in this case it makes the water dirty by throwing off a little scum from its own surface. It is better, therefore, to wait, till after having attained its greatest warmth, it shall have begun to cool a little, before you put it under water.

The setting of such cement balls may be much retarded, even to double the usual period, or more, if you mix the same calcined powder with a larger quantity of water, so as to form a thin or liquid instead of a stiffish paste; and in this case the heat thrown out will be diminished in the inverse proportion of the time required in setting: but eventually the slow setting ball becomes quite as hard as the others. I have ascertained by experiment, that one-fourth part of water to one part of cement powder by measure is necessary for making a stiffish mixture, whilst one-half measure of water to one measure of cement powder produces a very thin one. Between these extremes the proper proportion of water appears to lie. Less than one-fourth would not suffice to make up the whole of the mixture into a paste, whilst more than one-half would be inconvenient or injurious; for cement powder may be spoiled, or as it were drowned, if stirred up in a basin or bucket with excess of water; but this can never occur in practice, nor is any measurement of the proportional quantities of cement powder and of water either usual or necessary; for the expert bricklayer's or plasterer's labourer always mixes those ingredients together to the proper average degree of consistency, with very great accuracy, by the eye alone.

During the process of setting, experimental cement balls always throw out vapour, which may generally be seen rising from them, as long as the heat continues, and which moistens the surface of any dry substance on which they may be laid.

(48) The Sheppy cement stone is usually found in boulders or round nodules, and when dry is of a light brown colour. The Harwich cement stone is obtained in larger masses, and is of a dark bluish brown colour. When properly burned, the former is of a light brown, the latter of a nut brown colour. When the calcined powder of each is mixed with water for use, both mixtures are brown, but the former is of a much lighter tint than the latter, which approaches to blackness.

(49) Since cement from the kiln will not slake even with water, much less by the action of air alone, it might be preserved in this state for a long time in a dry room, as I have proved by experiment; but calcined cement being of no use until it is pulverized, this is always done at the mill of the manufacturer, to save the necessity of every purchaser providing himself with an apparatus for grinding it. This process, which enables water to act upon cement, makes it also subject to the action of the atmosphere.

(50) After calcined cement powder has been mixed up with water for use, it recovers in time the whole of the carbonic acid gas driven off by the fire. Hence the cement used for the purposes of Practical Architecture like the lime in mortar, is brought back but much more quickly, than the latter, to the same chemical state, as in the original stone. Hence also a fragment of old cement from a building will partially dissolve in the diluted acids, leaving a residue, and on reburning old cement and pulverizing it, the calcined powder thus obtained will be quite as good as that from the natural stone.

(51) Cement powder exposed to air, especially if damp, also gradually recovers the carbonic acid gas previously driven off from it; and whilst this process is in progress, it is injured, and eventually spoiled. For this reason the cement powder prepared for sale is always preserved in casks or sacks.

When cement powder, damaged by exposure to air, or from any other cause, has become too *stale* for use, it may be converted into good cement by reburning it, the practicability of which may be ascertained by burning some stale cement powder in a crucible in a common fire-place. But if any considerable quantity of damaged cement should require to be restored in this manner, as it could not conveniently be burned in a kiln whilst in the state of powder, it would be necessary first to mix it up with water into balls or lumps of a convenient size, which if allowed sufficient time will probably set so far as not to fall to pieces. If however the cement powder should be too stale for this purpose, let a small proportion of fine clay, not exceeding one-tenth part by measure, be added to it, in making these lumps, which will cause them to hold together in the kiln, without materially injuring the quality of the cement. It would not be worth while to take so much trouble in this country, but the knowledge of this expedient may perhaps be useful in some of the British Colonies, where cement is only obtained by importing it from England.

THAT THE MOST POWERFUL WATER CEMENTS ARE, LIKE LIMES, PARTIALLY DECOMPOSED BY AND SOLUBLE IN WATER, WHEN FIRST PREPARED FOR USE. THAT THIS ACTION IS TOO INSIGNIFICANT TO AFFECT THE SOLIDITY OF THE WORKS IN WHICH THESE CEMENTS ARE USED, AND THAT AFTER A CERTAIN TIME IT CEASES. CHEMICAL TEST FOR ASCERTAINING THIS POINT.

(52) When a cement ball made as above described is put immediately under water, it always throws off a little scum as was before mentioned, which partly falls to the bottom of the basin as a sediment, and partly rises to the surface in a very thin film, thus proving that the cement is partially decomposed by the separation of a part of the carbonate of lime, on being first immersed. If after a day or two the ball be taken out of the dirty water, and put into clean, the same effect will take place, but in a slighter degree; and on continuing to change the water from time to time, the films successively formed on the surface will become smaller and smaller, and at last imperceptible to the eye. When no apparent action of this kind takes place, wash your ball well in distilled water, and scrub it with a clean tooth or nail-brush, in order to get rid of any impurity on the surface of the ball; and when it is perfectly clean put it into a basin of distilled water, and let it remain there about a week. Then pour some water out of

the basin into a glass, and let a few drops of the oxalate of ammonia fall into it. If the water should still remain clear, it shows that the cement ball has now become proof against the action of water; but if a milky precipitate should take place, it shows that the unfavourable action of the water on the cement, at first clearly indicated by the scum thrown off from the surface, has not entirely ceased, for the presence of this precipitate proves that the water has dissolved a small portion of the lime belonging to the cement. Some recent experiments induce me to suspect, that balls made of the oldest and best natural cements, if kept in distilled water much longer than a week, would give out a slight precipitate. But the quantity of matter which they must undoubtedly lose in order to produce this effect is far too insignificant to be worthy of notice. Indeed without so very delicate a chemical test as the above, it would elude our observation. If you cannot obtain distilled water, clean rain water will answer the purpose, but no other should be used, because the water of wells and springs, and still more that of rivers, is always impure, and often contains lime in solution, which would of course defeat the object of this experiment.

It may require some weeks before the cement balls will cease to yield a copious precipitate with the oxalate of ammonia, though they will have set at the surface so as to resist the action of the nail, in a much shorter period. Before this degree of induration takes place, they will generally stain the back of the hand, or a piece of white paper, if rubbed against them after being wetted.

(53) Cement balls, if kept in the air after being made, throw out an efflorescence at first, which when seen in the sun or by candlelight is in the form of very brilliant crystals, but these, if washed off after a certain time, are never renewed. The same efflorescence is observable in the fronts of buildings, when first stuccoed with cement.

(54) That the partial decomposition by, and solubility in water of cement, especially when first prepared for use, is too insignificant to injure the solidity of wharf walls, and other works of hydraulic architecture, in which it is employed, may be admitted, not only from the circumstance that I have never observed any apparent diminution of the size of the experimental balls, made by me from the Sheppy or Harwich cement stones; for the marks of the printer's types, with which I usually impressed them whilst moist, have never been erased, although not penetrating more than about the twentieth of an inch, nor have even the lines

caused by the seams of the hand in kneading them into balls been entirely obliterated; but also from the well-known fact, that in wharf walls built with bricks and cement, no pointing of the external joints has been ever required, which would undoubtedly have been the case, had any perceptible decay of those joints occurred.

(55) In short, whilst the water cements and water limes are similar in their component parts and general properties, the great distinction between them, as applied to the purposes of hydraulic architecture, is, that the setting process at the surface comes so much sooner to full perfection in the former than in the latter, that the water, which after this period ceases to act perceptibly upon either, has not time to injure the external joints of the cement, but is enabled in the mean while to make a considerable impression upon those of the lime.

The greater solubility even of the water limes than of cement was proved to my satisfaction, by the following circumstance. The new vaults in part of the London Docks, built, under the superintendence of Mr. Palmer, then Engineer of that company, of brickwork laid in Dorking lime mortar, were left during the winter of 1827 exposed to the action of rain penetrating from above, as the warehouses by which they were intended to be covered were not then begun. Consequently I observed that this mortar, although very good of its kind, was giving way, for the lime in many of the joints had dissolved into stalactites, which hung from various parts of the vaulted roofs.* In the Thames Tunnel, on the contrary, no part of the cement in which the brickwork is laid has ever given way in this manner.

(56) We found by experiment at Chatham, that two-thirds of a cubic foot of calcined Sheppy cement powder, which is equivalent to one cubic foot of cement from the kiln, would not bear much more than one cubic foot and one-third part of a foot of sand, without evidently becoming too short for building purposes. This is equivalent to a mixture of two measures of sand to one of cement powder. But experience has shown that even this proportion of sand is too great in practice, for the builders of the metropolis, who have used immense quantities of the Sheppy and Harwich cements for

---

* The same lime would not have given way in this manner in a concrete foundation, or in the backing of a wharf wall, because these rest upon and are inclosed by solid materials on all sides, so that there is no vacant space, as in a vault, for the lime to fall into, or escape by. Consequently, as it cannot get away from its original position in combination with the sand and gravel with which it has been mixed, it sets in process of time without dissolving.

many years, agree that more than 5 parts of sand to 4 of cement powder, or 1¼ measure of the former to 1 measure of the latter, injures the cement, by retarding its setting and rendering it too friable, whether used as mortar for walls, or as stucco for the fronts of houses; but they consider that equal parts of sand and of cement powder, involving a smaller proportion of the former ingredient, are still better.

But not to lose sight of the just comparison between cement and lime, these proportions, when stated in the same manner as we did in treating of lime, imply that whilst *one measure of cement from the kiln will not bear more than two-thirds, or at the utmost five-sixths of a measure of sand without injury*, one measure of the various sorts of lime from the kiln, according to its quality, will bear two or three measures of sand or even more. (See Articles 9, 25, and 26.)

(57) There are two properties of cement, which ought to be thoroughly understood.

First. It only sets rapidly when made up into small balls or in very thin joints. In large masses or in thick joints, the rapid induration takes place near the surface only, from whence it extends towards the centre so very slowly, that the cement there may remain in an imperfect state for a very long time. This property it has in common with lime mortars and concrete, which when in mass set more slowly at the centre than at the surface, in the like proportion (33).

Secondly. As was before remarked in Article 42, cement is always weakened by sand, no matter how small the proportion of that ingredient may be; so that if both materials were equally cheap, it would be best to dispense with sand altogether in using cement as mortar for building walls, but not in using it as stucco for plastering the fronts of houses.

Numerous experiments have convinced me of the truth of these maxims, which any of my readers may easily verify. In respect to the latter in particular, take a small quantity of the best cement powder, mix it with three or four times its bulk of fine sand, and make it up into a ball with water, and you will find that instead of setting, it will remain friable or crumble to pieces, both under water and in air.

Upon the whole cement sets most quickly, and unites itself most powerfully to bricks or stones, when it is net or unmixed with sand, provided only that the joints be thin, I should say not exceeding half an inch in thickness. For this reason, in forming cement into chimney-pots, copings, &c., where the general thickness much exceeds the above dimension, and consequently where net cement alone would not make sound work, instead of frittering away its strength with sand, I would recommend fragments of broken tiles or gravel to be mixed with it, the interstices of which are such as to allow the cement which fills them sufficient body to attain a due degree of strength, without being quite so large as to retard its setting.

(58) This opinion is confirmed by the experience of the Thames Tunnel, where the justly celebrated Mr. Brunel,* who commenced differently, has finally adopted the system of using nothing but cement for all his brickwork, which he mixes with sand in equal measures for the foundation and lower part, and with half that proportion of sand for the piers which support his arches; but from the spring of the arches upwards, as being the most important part of the work, he uses only net cement. Indeed if the use of this admirable material had not been discovered, the execution of the Thames Tunnel would have been impracticable,† for if it had been attempted with the best mortar, the pressure of earth would have crushed some parts of the brickwork before the mortar got consolidated, and in other parts the lime would have been washed out of the joints, as was the case in a new basin in Chatham Dockyard, where several land springs washed the lime entirely out of those portions of the concrete foundation, which lay in their course, until those little rivulets were carried off by iron pipes leading to a culvert.

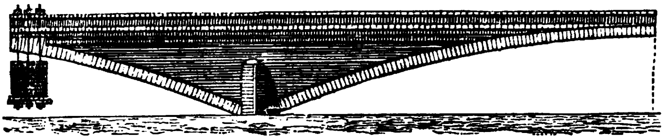
(59) But the remarkable strength of net cement is still more proved, and in a wonderful manner, by the two extraordinary brick semi-arches built for experiment by Mr. Brunel near the entrance of the Tunnel, which spread out from the same common central pier, like two immense branches from contrary sides of the trunk of a tree, one of which is 60 feet,

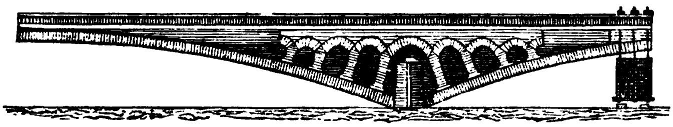
---

* Now Sir Mark Isambard Brunel, whose son, Mr. I. K. Brunel, has designed and superintended the construction of one of the most important railways in the kingdom, the Great Western, with all its branches and extensions.

† Under the protection of that most ingenious piece of mechanism, the massy iron shield, the brickwork of the Thames Tunnel is built in successive portions or ribs of 9 inches in length; but where the soil is bad, in portions of half that length only, which are connected by cement alone, the bricks of one rib not being toothed or bonded at all into those of the next. This defective bond, adopted from necessity, does not impair the strength of the work, because the judicious system followed renders it impossible that any new rib can separate from the brickwork previously finished, they being screwed up close together by means of the shield, for a space of time longer than is necessary for the intermediate vertical joints of cement to set, after which these joints become stronger than the bricks themselves, as I had an opportunity of observing in the beginning of the present year, 1836, when the brickwork laid in cement, with which the head of the Tunnel had been blocked up during the temporary suspension of the work, was cut away in order to continue the excavation. In this laborious operation, the solid bricks themselves were more frequently fractured than the cement joints.

and the other about 37 feet long, the rise of the former being 10½ feet, and of the latter, 10 feet; and this last is loaded at its extremity with a weight of 62,700 lbs., suspended below it, as shown in the annexed figures, which represent those





extraordinary semi-arches in elevation. The north side is plain, but on the south side seven small arches are shown, which on this side projected about 1 foot from the spandrils of the main semi-arches, or great ribs, as they may be termed.

The pier from which these semi-arches sprang measured in plan 10 feet in extreme length, and 4 feet in width, of which two dimensions the last only appears in elevation, and its extreme height above the same level was 8 feet. It was founded on Yorkshire paving stones, 3 inches thick, let into the ground only 8 inches below the surface. The semi-arches themselves were 3 feet 6 inches wide, and 13 inches in depth or thickness; and the cornice, with which one coincided, and the other nearly so, at their outward extremities, which were the respective crowns of these semi-arches, was also 3 feet 6 inches wide; but in the spandrils, or intermediate spaces on each side of the central pier, above the spring of each semi-arch, and below the cornice, the width of brickwork measured transversely was only 18 inches, that is, within the openings of the small arches, and not including the additional width caused by the projection of them or their piers.

The brickwork was bonded longitudinally with 10 tiers of 3 wooden pantile laths each, commencing at the height of 4½ feet above the level of the ground, and laid horizontally in the courses of the spandrils, above that level, over which it was further bonded with 11 longitudinal tiers of hoop-iron, laid also horizontally in the joints of the remaining courses of the spandrils, and in those of the cornice, in the following order as to number; viz., in the first or lowest of those joints 2 pieces of hoop-iron, in the second 3, in the third 4, in the fourth 5, in the fifth, sixth, seventh, eighth, and ninth, each 6, in the tenth 4, and in the eleventh 6 pieces, above which there was only one course of bricks more to complete the extreme height.

It is well known that the best cement alone will not hold together above a certain limited number of bricks thus unsupported, and therefore much must be ascribed to the laths and pieces of hoop-iron in the joints of the brickwork, the former of which, if secured against decay, Mr. Brunel considers quite as good as the latter for brick and cement bond: but unless cement had the property of setting almost instantaneously, and thus combining brickwork into one solid mass, having the joints and bricks of equal strength, the laths and hoop-iron could not possibly communicate such extraordinary stability to the same kind of brickwork hanging in the air. This ingenious arrangement of Mr. Brunel will probably be found hereafter of great value in practical architecture.*

These semi-arches having afterwards fallen down on the 31st of January, 1838, and this having been supposed at the time to have been in consequence of the frost of that severe winter, I took the first opportunity of inspecting the ruins, and of inquiring into the cause, which Mr. Brunel himself explained to me, and I found that no part of the brickwork or cement had been injured in the slightest degree by the frost. The fall of the semi-arches was solely occasioned by the foundation of the central pier, by which they were supported, having been deranged by excavating near it to a much greater depth for a gasometer and its fitments, and also by the ground immediately in contact with the brick footings of the pier having been frozen hard, and then suddenly thrown into a soft wet state by a thaw. Owing to these circumstances the pier moved, and the shorter of the two semi-arches descended, until the weights attached to it struck the ground, which caused a shock, and a sort of vibration, that broke off both of them, near to the pier from which they separated; but the shorter one, whose fall was soon arrested from the weights being very near to the ground, still remained in one mass, nearly in its original position, whilst the longer one, being at a considerable height from the ground, with nothing to break its fall, fell down, and was broken into eight or nine pieces, some of which were very large, two of them being not less than 40 feet long, when I saw them, but at this time the greater part of the ruins had been broken up into small masses, and removed from the spot, for the purpose of being used in the drains under the Tunnel. Mr. Brunel informed me that his semi-arches had been about four years in building, as he had from time to time added both to the length and width of brickwork first intended; and he observed that in falling the fractures had generally taken place at those parts, where the new work had been added to the old, where he considered the cement joints to be less perfect, in consequence of the surface of the old brickwork, to which the new cement was attached, having got smoked and greasy.

---

* Mr. Brunel proposed its application to the construction of large brick arches, without the necessity of previously constructing a substantial and expensive wooden bridge, technically termed *the Centering*, to support such arches until they are keyed in or completely finished; instead of which he used only a small light scaffold for the bricklayers, which was suspended from the finished part of the arch, and continually moved forward as the work proceeded. It occurs to me, that this ingenious invention of Mr. Brunel may be applied also to the construction of tunnels in loose soil, by carrying on the brickwork in oblique portions suited to the natural slope of the earth, instead of continuing it always vertically, which requires strong woodwork, for supporting the loose earth, until each new portion of brickwork is finished.

(60) The rapidity with which cement sets and dries in air, neither admitting of settlements nor producing damp in walls built with it, is no less advantageous in Domestic Architecture, by allowing an alteration or repair in a building to be made in the least possible time, and with the least possible inconvenience or injury to the health of the persons occupying it. By the use of cement, for example, the temporary Houses of Lords and Commons were finished in a dry wholesome state ready for use, in the short space of three months after they had been destroyed by fire in 1834, though the work was executed in a very unfavourable season.

(61) From the circumstance that all limes expand after being mixed with water, and in this process attach themselves firmly to sand, which increases their strength, whereas cement does not expand when mixed with water, and is always weakened by sand; it follows that whilst one measure of calcined Halling lime powder, with seven or eight measures of gravel and sand, may be a good proportion, it will require double the quantity of Sheppy or of Harwich cement powder to be mixed with the same quantity of gravel and sand, in order to produce concrete having the same superiority over Halling lime concrete, that cement mortar has over Halling lime mortar. This would involve a greater expenditure of a much more costly material without producing a better article for foundations and backing, than the common concretes, formed with the proper kinds of lime.

Hence cement should not generally be used for making concrete, but if employed for that purpose, in the only case that can render it necessary, that is, when the lower parts of a wharf wall or pier are to be built under water, without a coffer-dam, *one measure of cement powder may be mixed with a proportion of three, or not exceeding four measures of gravel and sand.**

(62) In building brickwork with cement, it is more usual, and excepting under circumstances of peculiar difficulty, it is certainly better to mix the cement with a moderate quantity of sand than to use it net, for this mixture diminishes the expense of the work, and is strong enough, as it produces joints equal in strength to the bricks themselves.

(63) Net cement has always been used as the finishing coat for the lining of tanks, and the coating of casemates, and we know that in both cases it has proved effectual, preventing leakage in the former, and rendering the latter perfectly dry. I am not aware that cement mixed with sand has the same property, at least I can certify that it is not water-tight, in the manner in which it is usually laid on by common plasterers. But for stucco this mixture is not only cheaper, but better than net cement, as being less liable to crack in setting, especially in hot weather when exposed to the sun. All the cement stucco, however, that I have seen, in spite of the admixture of sand, cracks more or less in process of time, which I conceive is partly caused by its not being sufficiently compressed by the workmen in laying it on, which they never will attend to, except in working at tanks or casemates, where the same careless manner, in which they execute their cement stucco, would inevitably occasion leaks. From this cause chiefly, the cement fronts of the new buildings in and near the metropolis, and indeed in every part of the kingdom, are completely reticulated by an immense number of fine cracks, which are usually superficial or *hair cracks*, but which elude observation from these fronts being afterwards washed over, or painted with some light colour, to take away the sombre hue of the natural cements. But unless the cement stucco should peel off from the face of the wall, which sometimes happens when very unskilfully applied, these hair cracks on its own surface do no harm.

---

* In the fine brick viaduct of 19 semicircular arches of 30 feet span, for passing the South Eastern Railway over a deep valley and stream near Folkstone, the five centre arches have a foundation of concrete, and over it inverted arches of brickwork laid in cement, protected by sheeting piles both above and below, against the action of the water. The concrete was composed of 1 measure of cement powder and 6 of beach shingle and sand, which gave satisfaction; but I apprehend that a much cheaper concrete, made of a smaller proportion of grey chalk lime with the same quantity of shingle and sand, would have been equally good.

It may appear scarcely necessary to mention, that casemates, to be coated with cement, must not be liable to after settlements, which would crack the masonry or brickwork, and consequently the cement itself, which is a non-elastic substance, and thereby occasion leaks.

OF SLOW SETTING CEMENT STONES, SUCH AS THE BLACK ROCK OF QUEBEC. THAT THEY MAY BE USEFUL UNDER PARTICULAR CIRCUMSTANCES.

(64) The Sheppy and Harwich cements, when made into moist balls, begin to set almost immediately, whether in air or under water, and in the course of half an hour, or sometimes much less, they emit that clear ringing sound, which is a proof of hardness, on being thrown against the side of a basin; and no water cements inferior to these would be accepted in the English markets. But it is possible that a less powerful water cement might have its value in other countries, if found abundantly in any district, where superior water cements, or the ingredients for imitating them by artificial means, were not to be conveniently obtained.

For example, a number of specimens of what is called the black rock of Quebec were recommended as being good water cements, by Captain Baddeley, of the Royal Engineers, to the Master-General and Board of Ordnance, by whom I was ordered to examine and report upon them. Accustomed only to the powerful water cements of England, I should have rejected the whole of them at once, if the respect, which I considered due to the opinion of another officer, had not induced me to give more time and care to their examination, than I had ever done to any former specimens of natural stone supposed to have cement properties. The quantity of carbonate of lime contained in most of them was evidently too small, since on being immersed in the diluted muriatic acid they did not always fall to pieces, but retained their original form as solid fragments of stone, after all the lime had been dissolved, and the carbonic acid gas driven off with effervescence. And on being burned in the fire, and afterwards pounded, and made up into moist balls in the usual manner, they threw out very little heat, showing scarcely any symptom of setting, and remaining as a soft pulpy mass under water. But on giving them longer time, by allowing them to remain several days in the air, I found that they had acquired a stony hardness, and on then putting them into a basin of water it had little or no effect upon them, and finally, after having kept them one or two months longer, and immersed them when perfectly clean in distilled water, for several days, I found that the oxalate of ammonia produced no effect upon this water, which afforded the most satisfactory test of their quality. Indeed they yielded less to this test than our best English water cements had done under the like circumstances. I recommended, therefore, that the specimens reported by me as being the best, for some were very indifferent, should be tried on a greater scale at Quebec, by burning a sufficient quantity in a kiln, to be used in the first Government work in which water-proof cement might be required, but not in tide-work, for which I considered that the slowness of their setting rendered them less suitable.*

Having now explained the properties of the water limes and cements of nature, I shall proceed, as I before promised (3), to describe in sufficient detail the course of experiments upon artificial water cements, which occupied a portion of my time for several successive years.

OF THE SYSTEM PURSUED IN THE EXPERIMENTS FIRST TRIED ON A SMALL SCALE IN CRUCIBLES, IN 1829 AND 1830, IN ORDER TO FORM ARTIFICIAL WATER CEMENTS, BY VARIOUS COMPOUNDS.

(65) After having succeeded by accident in making a good water cement with chalk and blue clay, as stated in Article 2, and having given a good deal of time to the chemical analysis of the natural cement stones, which I found attended with the difficulties before alluded to (43), and which led to no satisfactory result, I determined to relinquish this unpromising investigation, and to adopt the system of working synthetically, by combining together all the substances likely to form an artificial cement, first by twos, and afterwards by threes and fours, in various proportions, determined generally by measure, not by weight. All the natural stones, and other dry substances experimented upon, were measured in the state of impalpable powder to which they were previously

---

* It is rather curious, that Captain Baddeley, who suspected the black rock of Quebec to be a water cement from its chemical properties, could not succeed in making it available as such, until he read my observations on water cements, printed by authority for the use of the Royal Engineer Department in 1830, whilst on the other hand his recommendation of this stone led me to the conclusion, that very slow setting water cements, such as I would before have condemned, are not without their value under particular circumstances. On receiving a copy of my Report, he wrote that he had ascertained that this cement becomes water-proof in about six hours after being mixed, instead of requiring some days, as I supposed. Not having tried the precise period in which this effect took place, and having no more specimens of the stone to experiment with, I cannot verify this fact personally; but I have no doubt of the correctness of Captain Baddeley's statement.

reduced by pounding them in a mortar. The natural clays and some other substances were measured in a moist state. The powders were dropped or thrown into the measure with sufficient force to fill every part of it, and were stricken by scraping off all that stood above the rim; but they were never rammed or pressed down. Each of the measures used was open at bottom as well as at top, and laid on a slab whilst being filled, and the clay or moist substance was not only put into it by one of those open sides, but by the other also, after inverting the measure, without which we found that vacant spaces were always left. When thus put in and stricken on both sides of the measure, it was forced out by a wooden plug fitting the opening, but of about double its height.

After measuring the several ingredients, we mixed them intimately together, adding a moderate quantity of water, with a spatula upon a slate or porcelain slab; after which we made them into balls of about one inch in diameter, and dried them for a little while before the fire, until they would not stick to one another, after which we put as many of them into a Cornish crucible, as it would hold, and burned them for about three hours in a common fire kept up to a full red heat.

We found that the ingredients cannot be pounded too fine or mixed too well, and that water is absolutely necessary. If imperfectly pulverized or mixed carelessly, the most suitable ingredients may fail, and if mixed dry and burned in a crucible, they will also fail.

(66) To prevent our crucibles from breaking by sudden changes of temperature, we heated them gradually before we exposed them to the full degree of heat necessary, and after taking our calcined cement balls out of them, we put them into the fire again, and by diminishing the heat allowed them to cool gradually. We always purchased covers with our crucibles, and when they broke we replaced them by iron ones.

(67) To judge whether our artificial cement mixtures were burned enough, we followed the same rule as in burning the natural cements (45). Taking our crucible out of the fire, we dropped a fragment of one of the balls contained in it into a glass of diluted muriatic acid. If it effervesced violently, which proved our mixture to be underburned, we put it into the fire again: but if it did not effervesce, and was not burned darker than its original colour, we considered it burned just enough, and not more than ought to be.

(68) We therefore next proceeded to pound our calcined cement balls in a mortar, until we reduced them to the state of an impalpable powder, leaving no gritty particles when rubbed between the finger and thumb, after which we made our calcined cement powder into moist balls with water, proceeding exactly in the same manner as in trying the quality of the natural water cements (46 and 47).

(69) All our experimental balls of calcined cement powder, whether natural or artificial, were marked with printers' types, whilst in a soft state, before they heated and set, the letters and numeral figures impressed upon them showing, by appropriate abbreviations, the component parts and proportions of each ingredient, and the day of the month and year when they were made. Without this precaution the record book of our experiments, which was kept in the form of a journal, would have been of little use. The types necessary for marking each ball must always be arranged beforehand, and used without delay, because the natural cement stones of England, and the best artificial compounds, when burned in a common fire-place, set so quickly that there is no time to spare. We also marked the raw mixtures previously to burning them, when several sorts were experimented upon at the same time.

(70) As all our experimental balls of calcined cement, with some few exceptions which shall be noticed hereafter, were put into a basin of water soon after they were made and marked, those which failed in setting permanently did so under various circumstances. Some of them fell to pieces in a state of powder at the bottom of the basin, without any apparent separation of the lime, or action upon it by the water. Others fell to pieces after swelling to a much greater size. Some appeared to set in the most promising manner, but afterwards cracked and eventually split to pieces, or became soft throughout. These results took place almost immediately in some mixtures, but not until after several days or even weeks in others, and in all cases films of lime formed at the surface of the water, unless the defective mixtures were thrown away immediately. Some mixtures hardened at the surface only, proving soft inside on being broken, after having been made several weeks. We therefore adopted the rule of breaking all our artificial cement balls with a hammer and chisel, in a month or two after they were made, and if we did not then find the inside of a stony hardness, we considered the cement an imperfect one.

In order to obtain this result of perfect hardness throughout, it is however absolutely necessary that the experimental balls of calcined cement shall not exceed one inch in diameter, because, as was before observed (57), the induration of the central parts of larger masses of cement is tardy, and analogous to the gradual induration of common mortar.

THAT ON REPEATING THE SAME EXPERIMENTS IN 1836, IT WAS FOUND MOST CONVENIENT NOT TO USE CRUCIBLES.

(71) Having presented numerous specimens of the artificial cements made by me in 1829 and 1830, to the Royal Institution, to the Institution of Civil Engineers, and to some other Scientific Societies, without keeping duplicates of all, I was induced at the beginning of the year 1836, to repeat most of those experiments, not only to obtain new specimens of those that were deficient, but to verify generally the most important results; and having in these more recent experiments dispensed with crucibles, in all those mixtures which were of a plastic nature, and therefore not liable to crumble to pieces in the fire, which I had seldom done in former years; I consider this upon the whole to be not only the most economical but the best mode of proceeding, and I therefore recommend it to any of my readers who may be disposed to try similar experiments. In using this method it is best to make up the raw cement mixtures into balls of about two inches and a half in diameter, with a moderate quantity of water. If they should split a little in the fire, which sometimes happens, it is of no importance; and if the surface should be blackened with smoke, let it be scraped off before the ball is pounded, and no harm will be done, but this circumstance only occurs in a dull fire, which ought not to be used.*

OF THE INGREDIENTS WHICH WERE USED IN OUR EXPERIMENTS.

(72) The ingredients used in our experiments were as follows.

First, Carbonate of Lime. For this, which is the most important ingredient in all water cements, whether natural or artificial, we used pounded chalk.

Secondly, Silica. For this we used pounded flints, previously heating them red-hot and then quenching them in water, according to the custom of porcelain manufacturers, without which they cannot conveniently be pulverized.

---

* Rather more care is necessary in burning the natural cement stones, or any other hard stones, without crucibles than with them, owing to the tendency of these stones to burst into small pieces in the fire; but this is easily prevented after a little practice in such experiments. (See Article 45.)

Thirdly, Pure Alumina. This was partly purchased in London, and partly made for us by a chemist in Rochester.*

Fourthly, Silica and Alumina. For this compound we sometimes used Dorsetshire pipe clay, the purest natural combination of these two ingredients; sometimes a mixture of pounded flints and pure alumina.

Fifthly, The Protoxide of Iron. For this we used the scales struck off from their iron by the anchorsmiths in Chatham Dockyard, which we reduced to fine powder by pounding them in a mortar.

Sixthly, The other Metallic Oxides, Carbonates, &c. We purchased the peroxide of iron and the other metallic oxides, as well as the calcined magnesia and the carbonates of magnesia, soda, potassa, &c., used in our experiments, in the state in which they are usually sold by the chemists, and of the best quality.

Not only the clays as before mentioned, but the pure alumina, and the carbonate of magnesia, were measured moist. The pulverized chalk, the other carbonates, and all the metallic oxides, were measured dry.

OF THE MIXTURES, WHICH SUCCEEDED OR FAILED IN MAKING GOOD ARTIFICIAL CEMENTS.

(73) *Carbonate of Lime and the Metallic Oxides.* A calcined mixture of pounded chalk with the protoxide of iron generally fell to pieces, but in some few cases it hardened a little under water, but never so as to form a cement, for it was easily broken by the fingers, and always dirtied the hands. A mixture of pounded chalk with the peroxide of iron also generally fell to pieces, but occasionally formed a soft mass that never hardened under water. A mixture of pounded chalk with the oxides of manganese would neither harden nor adhere together, but always fell to pieces under water.†

(74) *Carbonate of Lime and Silica.* This mixture did not succeed in forming a water cement above once in ten trials in former years, but it succeeded frequently on repeating the

---

* Mr. Tatum, who informed me that for this purpose he dissolved a quantity of alum or sulphate of alumina in distilled water, and added subcarbonate of soda to the solution until the acid was neutralized, after which he obtained the pure alumina by repeatedly washing, and then drying the precipitate with heat.

† All the mixtures mentioned are supposed to have been calcined or properly burned in the fire unless the word *raw* be prefixed, which denotes an *unburned* mixture.

same experiment now, although the cement formed by it seldom set into a very sound substance under water. I can only account for the difference in these results by supposing that the flints formerly used may have been badly pounded, which defect is sure to produce failure or imperfection in all such experiments, but which I know was not the case now. In this mixture, the chalk and silica previously to adding the water being both in the state of dry powder, it was most convenient to determine their properties by weight, and we found that equal weights of these two ingredients produced the most satisfactory result. On afterwards ascertaining the proportions of the same quantity of each ingredient by measure, we found that it was nearly equivalent to a mixture of 2 measures of dry chalk powder with 1 measure of flint paste, by which I mean the same flint powder mixed up with water into the consistency of moist clay.*

(75) *Carbonate of Lime and Alumina.* This mixture always succeeded now in forming a water cement, of a white or greenish colour, but not of a very hard sound nature; and of all the proportions tried, a mixture of equal measures of pulverized chalk and of alumina paste proved the most satisfactory.† It had almost always failed in former years, from our having used only about half of the above proportion of alumina.

(76) *Carbonate of Lime and Carbonate of Magnesia.* When pulverized chalk and the moist carbonate of magnesia were mixed together and burned, in any proportion of the latter ingredient not containing less by measure than one-half of the former, they formed an imperfect cement, which if kept a day or two previously to immersion did not always fall to pieces in a basin of water, but seldom or never set well either in air or under water. On using a greater proportion of magnesia, by combining equal measures of chalk powder and of magnesia paste, the mixture did not always fall to pieces on immediate immersion, and it even set sometimes into a very sound close-grained cement.

---

* Mr. Frost, whose operations were before noticed in Article 4, had actually formed an artificial stone of this mixture, before I commenced my course of experiments.

Dry chalk powder averages in weight about 175 Troy grains per cubic inch. With 10 cubic inches of chalk powder mix about 2½ cubic inches of water, and the chalk paste thus formed will occupy only about 5 cubic inches.

Dry flint or silica powder averages about 280 grains per cubic inch. With 10 cubic inches of this powder mix about 3½ cubic inches of water, and the flint paste thus formed will compress into about 7½ cubic inches.

† Dry alumina powder averages about 80 grains per cubic inch. With 10 inches of this powder mix about 5 cubic inches of water, and the alumina paste thus formed will compress into about 6¼ cubic inches.

(77) Upon the whole, all the double compounds, formed by mixing the carbonate of lime with one other ingredient only, proved rather unsatisfactory, as the two best of them, namely, the mixture of chalk with silica, and the mixture of chalk with alumina, did not produce a very good water cement, and the mixture of chalk with magnesia did not always succeed, whilst the others invariably failed.

(78) *Carbonate of Lime, Silica, and Alumina.* Four measures of pounded chalk, 1 measure of flint paste, and 2 measures of alumina paste, being a compound of the two mixtures described in Articles 74 and 75, always succeeded in setting under water, and seemed rather better than either of these mixtures singly.* But still more satisfactory results were obtained from a mixture of 5 measures of pulverized chalk, and 2 of pipe clay, the latter in the state of a stiffish paste.

(79) *Carbonate of Lime, Silica, and Alumina, with the Protoxide of Iron.* To each of the two mixtures described in the preceding Article, we added various proportions of iron, from about one-tenth to one-hundredth part of the whole compound, all of which proved satisfactory, but especially a mixture of 5 measures of chalk, 2 measures of pipe clay, and about one-half or one-third part of a measure of the protoxide of iron, which produced excellent water cements of a light bluish grey colour; but in consequence of the peculiar hardness of those mixtures after calcination, we found that the pounding of them required very great care and more than usual labour, which persons when first employed in such experiments are sure to neglect, and which, if neglected, becomes, as I must again repeat, a certain source of failure or imperfection.

OF THE ESSENTIAL COMPONENT PARTS OF AN ARTIFICIAL WATER CEMENT. THAT THEY MUST BE IN THE FINEST POSSIBLE STATE OF IMPALPABLE POWDER OR OF PASTE.

(80) Knowing that the natural water cements are chiefly composed of the carbonate of lime, silica, alumina, and the oxides of iron, I had now by working synthetically with all these ingredients obtained an artificial water cement apparently no less perfect; and it appeared that next to the carbonate of lime, which is indispensable, silica and alumina

---

* From the nature of these two mixtures, there can be no doubt, that any combination of the two will form a water cement, though I only tried them in the proportion stated, which implies 2 parts of pounded chalk with an equal weight of silica powder, and 2 parts of pounded chalk with an equal measure of alumina paste, all mixed together with water.

were the most important ingredients; for these made a water cement without the iron, whereas the iron never succeeded without them, notwithstanding which, it was of great use, since it caused them to set more quickly, and at the same time communicated to them a superior degree of compactness and hardness.

I must here observe most decidedly, that no artificial mixture, however judicious, will make a water cement, unless the solid ingredients be reduced to the state of impalpable powder, and unless the moist ones also be in the finest possible state, previously to being burned.

EXPERIMENTS CONTINUED.

(81) *Carbonate of Lime, Silica, and Alumina, with other Metallic Oxides.* We next tried the same mixture of chalk and pipe clay with other metallic oxides. The addition of the peroxide of iron occasionally formed a good cement, but the success of this mixture is very precarious. The addition of the oxides of manganese or of red lead always formed good cements with the same ingredients.

(82) *Carbonate of Lime, Silica, and Alumina, with the Carbonate of Magnesia.* On mixing 5 measures of pounded chalk, 2 measures of pipe clay, and from 1 to 5 measures of the carbonate of magnesia together, they formed an excellent artificial water cement, and the same satisfactory result was obtained on using a somewhat smaller proportion of magnesia. This cement, when moderately burned, was of a handsome white colour, but when burned rather more it assumed a darkish slate colour; and we ascertained by some recent experiments, that it was equally good in both those states. Hence I suspect that cement a little overburned may not be materially injured, provided that no part of it is vitrified; but in former years having always thrown away those mixtures which were burned to a darker colour than usual, I cannot speak with certainty as to this point.

To return to the carbonate of magnesia, it thus produced as an ingredient in a water cement, the same favourable effect as the protoxide of iron, or perhaps it may be pronounced superior to it or to any other metallic oxide, inasmuch as the carbonate of magnesia sometimes combined with the carbonate of lime alone into a good water cement (76), which none of the metallic oxides were capable of effecting.

(83) *Carbonate of Lime, Silica, Alumina, and the Metallic Oxides, as obtained by a mixture of Chalk and the Clays of nature.*

First, Chalk and blue alluvial Clay. This mixture of pounded chalk and of blue clay from the Medway, although the first of my artificial cement mixtures, which succeeded, is placed here amongst the quadruple compounds, after several of the others. I need scarcely say that the chalk supplies the carbonate of lime, whilst the blue clay furnishes the silica, alumina, and the protoxide of iron.

Having tried various proportions of these ingredients, I finally adopted 5 measures of chalk to 2 measures of moist clay, as being that which produced a cement most similar to the Sheppy cement in its qualities.*

Considering the clay as unity, the chalk thus used is 2½ times the measure of that ingredient. Three measures of chalk to one of clay will also make a water-setting cement, but not so good as the former proportion. A greater excess of chalk, such as 3½, 4, or 5 to 1, spoils the mixture as a water cement, but converts it into a water lime. A smaller proportion of chalk, on the contrary, such as 2 to 1, makes a very good water cement, and even 1½ measure of chalk to 1 of clay makes a good cement, but one that sets with moderate heat and very slowly, for according as the proportion of chalk is diminished, the heat in setting is diminished also, whilst the period required for this process is prolonged.

The artificial cement balls formed of chalk and blue clay are of a lightish brown colour, but when put into a basin of water, the lower surface, if in close contact with the basin, is sometimes green, and on breaking one of these balls the inside also is sometimes green, but after the fractured part has been exposed to air, it assumes the light brown tint of the original surface.

When tested by the oxalate of ammonia in the manner explained in Article 52, the artificial cement made with 2½ measures of chalk and 1 of blue clay, appears to be acted upon by water, in the same degree nearly as the Sheppy or Harwich cements.

(84) *Secondly, Chalk and the brown alluvial Clay or surface Clay of Rivers.*

The alluvial clay, which abounds in estuaries near the mouths of rivers, consists of soil washed away from the upper country after rains, which being then held in suspension in the stream, according to the chemical phrase, is deposited on the beds of those rivers, near the sea, where the current is usually more moderate. In its original state it is of the natural brown or reddish brown colour of the soil, and the surface or upper part of it, which is exposed to the air at low water, always retains the same colour for about an inch in depth, but the remainder of it, which is inaccessible to free air, acquires a dark blue colour approaching to blackness. Thus the great mass of alluvial clay is blue, whilst the surface only is brown.*

---

* In more accurate experiments afterwards tried, a smaller proportion of chalk was found to make better artificial cement, and a more correct mode of determining the comparative quantities of the two ingredients was adopted.

Having tried a mixture of pounded chalk and of the brown alluvial clay or surface clay of the Medway, it made, apparently, an excellent cement, which set under water immediately, but after a few days it began to crack at the surface, and eventually fell to pieces in about a week.

THAT BLUE CLAY, OR ALLUVIAL CLAY FRESH FROM A RIVER, IS AN EXCELLENT INGREDIENT FOR A WATER CEMENT, BUT THAT IT LOSES THIS PROPERTY, IF KEPT UNTIL IT BECOMES STALE.

(85) *Chalk and stale alluvial Clay.* The blue alluvial clay, treated of in the preceding Article, when taken out of a river and exposed to air, loses its dark blue colour, which such exposure gradually changes to the same light brown tint that distinguishes the surface clay, after which it also loses its powerful cement properties, and may then be termed *stale*, in contradistinction to its original state of *fresh alluvial clay.*

Wishing to ascertain how much of this clay consisted of solid matter, I weighed it repeatedly when fresh from the river, and finding that its average weight was 87 ℔s. per cubic foot, I dried it carefully on iron plates without burning it, and ascertained that it lost eleven-twentieth parts of its weight nearly; so that more than one-half of the blue clay of the Medway must consist of fluid or volatile matter. The very offensive smell emitted during the process of drying it, led me to suppose that fresh alluvial clay must contain a much greater quantity of hydrogen gas than I had before suspected, which proved to be the case in an experiment afterwards tried by me, in which I was kindly assisted by Mr. Griffiths,† and I believe that the escape of this gas, which is of course facilitated by exposure to air, is the chief cause of the change of colour from blue to brown, during the transition of the alluvial clay from fresh to stale, which robs it of its cement properties. But as this change is gradual, it is proper to explain under what circumstances it takes place, and how one may judge whether its injurious effects have come into full operation.

---

* The same effect is observable in drains after violent rains. The fluid mud washed away from the roads is of a brown colour, whilst running in gutters exposed to air, but after falling into covered drains, where it is no longer accessible to the free action of the atmosphere, it acquires the same dark blue colour belonging to alluvial clay, as may be observed from time to time when the sesspools of such drains are cleared out.

† Who had formerly been the assistant of Dr. Faraday, in the Chemical De-

(86) When blue clay fresh from the river is mixed with chalk, and made up either into balls for burning in the fire, or into larger lumps or cubes for burning in a kiln, the colour of the clay predominates so much over that of the chalk, that these balls or lumps are still of a darkish blue or slate colour, but the air very soon changes the outside of the mixture to a light drab or dirty white colour; and by degrees this change extends from the surface inwards, until it takes place throughout the whole mass, which it does sooner or later in proportion to the smaller or greater size of the ball or lump, and at this period of total change of colour, the mixture will have entirely lost its powerful cement properties. In small experimental balls of about an inch in diameter, exposure to air for about 24 hours only in a dry room, previously to burning, will injure the mixture, and 48 hours will spoil it; whereas in balls or cubes of about 2½ inches diameter or side, exposure to air for ten or twelve days will not materially injure it.

As a change of colour at or near the surface only is of little importance, if you break one of the balls or lumps of this mixture prepared for burning, and examine the colour of the inside, you may always judge whether it still retains or has lost its power of forming a good water cement.

(87) *Chalk, stale alluvial Clay and Coal-Dust, or other combustible Material.*

It having been suggested to me by an eminent Chemist, to whom I mentioned the success of the fresh and the failure of the stale alluvial clay, that it probably was occasioned by the iron in the clay having gradually changed from the state of protoxide to that of peroxide,* and that the addition of pulverized charcoal or coal-dust, to the raw cement mixture injured by air, might, by promoting a contrary change in the iron during the process of calcination, correct this defect;

---

partment of the Royal Institution, and was then delivering a Course of Lectures on Chemistry at the Philosophical and Literary Institution of Chatham and Rochester. Mr. Griffiths's Report on the blue clay of the Medway is annexed in the Appendix.

* This was long before the presence of hydrogen gas, in any considerable quantity, as a component part of the blue clay, was suspected by me.

I proceeded according to his advice, after having mixed chalk and stale alluvial clay together in the usual proportion, to add various proportions of charcoal powder and coal-dust, and when the latter was not less than one-fifteenth part by measure of the whole compound, it generally produced the favourable effect anticipated by the distinguished individual alluded to, and I found that the same result was obtained by adding any other combustible matter, such as rosin, soot, sawdust, or oils and tars of various sorts, to the raw mixture of chalk and stale alluvial clay.

(88) *Chalk, stale alluvial Clay, and the Protoxide of Iron. Chalk, stale alluvial Clay, and the Carbonate of Magnesia.*

On adding the protoxide of iron, or the carbonate of magnesia, to the raw cement mixture of chalk and stale alluvial clay, these ingredients also improved the mixture, and appeared to restore its original virtue to the clay.

(89) *Chalk, blue or fresh alluvial Clay, and Coal-Dust.* Under an impression that blue alluvial clay was the best ingredient that could be used for forming an artificial water cement, in combination with chalk, and having ascertained that when this mixture became stale and gradually lost its virtue, it might be restored by remixing it with some of the substances mentioned in the two preceding Articles, it appeared desirable to ascertain whether any of those ingredients would act as a preventive to the same evil, which, by saving the necessity of a second mixing, would obviously be better than to allow the raw cement to spoil first, and to cure it afterwards. But it seemed evident that iron would be of no use as a preventive, because the same exposure to air which injured the alluvial clay would also spoil the iron, by changing it from the protoxide into the peroxide; and most of the other substances, especially the carbonate of magnesia, were too expensive. It therefore occurred to me, that a proportion of fine coal-dust, if mixed with the proper proportions of chalk and of blue clay in the first instance, although it would not prevent the clay from being injured by exposure to air, yet that it would, during the process of calcination, remedy this evil, and produce as good cement as if the clay had not been allowed to become stale; and it also seemed probable, that the proportion of coal-dust used in the original raw cement mixture might not be altogether wasted, but might assist in the burning of the cement. Under these impressions, I was of opinion for more than a year, during the course of my crucible experiments, that the best artificial cement mixture consisted of 5 measures of pounded chalk, 2 of blue clay,

and half a measure of coal-dust, and in working on a greater scale I frequently adopted these proportions; but afterwards, on allowing a mixture of this kind to dry for a year, we found that the air had spoiled it also, and that it required an additional proportion of coal-dust, much greater than the first, to restore the mixture thus deteriorated; so that in this case, the coals mixed with the chalk and clay at two successive periods, together with the coals required in burning the mixture, more than doubled the expenditure of coals that would have sufficed for the latter purpose, if the mixture of chalk and blue clay alone had been put into the fire soon after it was first made up, without allowing time for the air to spoil it.

(90) *Chalk and washed alluvial Clay.* It occurred to me at one time that the mixture of chalk and blue clay, if washed repeatedly by stirring it up with a great excess of water, and then allowing the mixture to subside to the bottom, and draining off the clear liquor from the top, might thereby be greatly improved, and yield a better cement after calcination. This process however produced the same injurious effect upon the clay as exposure to air, and I believe in both cases, that it results not only from a change in the state of oxidation of the iron in the clay, as stated in one of the preceding Articles (87), but also from the escape of the hydrogen gas contained in the clay being facilitated by its diffusion through a great quantity of water, during the process of washing, which causes the same quantity of fresh alluvial clay to become stale, much sooner than exposure to air alone would do (85).

(91) *Chalk and brown Pit Clay.*

By the term *Pit Clay*, in contradistinction to the *Alluvial Clay* of rivers or lakes, I mean clay dug out of the ground, not including the surface, which even when free from vegetation is never used for pottery or brickmaking.

It was before mentioned, that our first efforts to make a water cement by a mixture of chalk with an excellent brown brick loam entirely failed (1), whilst the mixture of chalk and of blue alluvial clay succeeded (2). On endeavouring to analyze those earths, but without reference to the quantity of gas that might be contained in either, to which I did not turn my attention till long afterwards, I found that they both contained silica, alumina, and the oxide of iron; and the only apparent difference, which I could at that time discover, was after repeated washings, when I found that the blue clay contained a very small portion of fine white sand, whereas the brown clay contained a considerable proportion of coarse gritty sand. I therefore pounded the brown clay in a mortar, until I made it as fine as the blue, after which, on mixing it with pulverized chalk, it formed a good cement. The same result occurred, on separating the coarse sand from the brown loam without pounding it. Thus an important rule in artificial cement-making came to light, that only the finest clays of nature are fit for that purpose, agreeably to the principle that various substances are capable of chemical combination, when reduced to an impalpable powder, but in no other state.

(92) On experimenting afterwards with other brown or reddish brown clays of a sufficiently fine quality, from the high ground between Upnor and Hoo, they all formed good water cements, with chalk, in the usual proportion of 5 measures of the latter to 2 of the former; and these pit clays have the advantage of not losing their cement properties by exposure to air so soon as the alluvial clay, for whilst a month or six weeks will ruin the raw cement cubes made of the latter, it may require two or three times as long to ruin the former. Indeed the fine brown clays are so much less liable to injury from this cause, that I entertained great doubts whether the air affected them at all, until I found that the same mixture of chalk and of fine brown pit clay, from which I had made a considerable quantity of excellent cement, entirely failed seven months afterwards, on my burning some cubes of the same mixture, which I had preserved for this purpose. In one respect the brown clay cement mixtures are much inferior to the blue, inasmuch as the former burn into a much harder substance, and require more labour in pulverizing them afterwards than the latter, which is a very great disadvantage both in a natural and in an artificial cement.

There being no blue pit clays in the neighbourhood of Chatham, though they abound in other parts of England, I have not tried any of them, but I have no doubt of their efficiency; and upon the whole it appears to me, that any fine clay, whether alluvial or not, will make an excellent water cement in combination with chalk, provided that it shall not have been subject to the free action of the atmosphere, either from its original position being at the surface, or from subsequent exposure.

(93) *Chalk and Tile-Dust.* Tiles being usually made of the fine brown pit clay, which I found to be a good ingredient for an artificial cement, I tried various proportions of pounded chalk and pounded tile-dust, mixed together with water, and then burned in a crucible in the usual manner, all of which failed, with only one exception, being greasy to the touch, and either going to pieces or not setting under water.

(94) *Chalk and Slate-Dust.* As roofing slate, according to the Mineralogists, is merely clay in a hardened state, both containing the same component parts,* I tried various proportions of chalk and of pulverized slate, treated as in the preceding Article, which formed an imperfect cement, that after being kept under water for some weeks crumbled to pieces on being taken out.

(95) *Chalk and Fullers' Earth.* The same reason induced me to try the fullers' earth of Reigate, which is reported also by the Mineralogists to consist of the same component parts as slate nearly.† But the mixture of chalk with this earth entirely failed.

Hence as slates, which are without plasticity, and tiles, which have lost that property in the fire, always failed, whilst the component parts of the same substances, namely, silica, alumina, and oxide of iron, as contained in the clays of nature, always succeeded in forming an artificial cement in combination with chalk; I inferred that plasticity was essential to an artificial cement, especially as the want of this property seemed also to be the chief cause of the failure of the fullers' earth, which when made up into a form with water is not plastic, but splits in drying in the air, and when burned in the fire with every precaution, instead of forming a sound brick, breaks into a number of small fragments in the state of porous unsound slag or scoriæ. But on washing the fullers' earth repeatedly, in order to get rid of the small portion of salt, also said to form a part of that substance, we found that it became more plastic, and in this state it frequently succeeded in forming a water cement, but inferior to that of the plastic clays.‡ The same cause may perhaps account for the superiority of pipe clay, which possesses great plasticity, over the mixture of pounded flints and prepared alumina, which had none.

---

* According to Kirwan, it contains silica 38, alumina 26, magnesia 8, lime 4, and peroxide of iron 14 parts in 100. See Jameson's Mineralogy.

† According to Klaproth, it contains silica 53, alumina 10, magnesia 1·25, lime 0·5, muriate of soda 0·1, potassa a trace of, oxide of iron 9·75, and water 24 parts in 100. See also Jameson's Mineralogy.

‡ This experiment proves the utility of the common practice of passing the earths used in brickmaking through the washmill. The blue clay of the Medway burns into a hard sound brick, but it is too fine, or, as brickmakers term it, *too strong*, for the common purposes of brickmaking, for which they prefer a *milder*, that is, a coarser clay.

THAT HARD LIME STONE, IF USED AS AN INGREDIENT FOR A WATER CEMENT, MUST BE BURNED TWICE, FIRST IN ITS NATURAL STATE, AND AFTERWARDS SLAKED AND MIXED WITH CLAY.

(96) The only very soft lime stones that I am acquainted with are chalk and a yellow magnesian lime stone, of which I procured a specimen from the Geological Society, and which appeared rather softer than chalk. In preparing these as ingredients for an artificial cement, the obvious mode of proceeding is to grind them into fine powder; but if we suppose it necessary to make an artificial cement in some country, where none but hard lime stones are to be procured, which I believe must have been the case in those districts of France where M. Vicat was employed, the grinding becomes such a troublesome and expensive process, that the simplest mode is first to burn those hard lime stones and slake them, in order to reduce them to a more tractable form, and then to mix them with clay and burn them a second time, to obtain the artificial cement desired. This was the system adopted by M. Vicat, no doubt from necessity, and which I thought it desirable to investigate for the sake of experiment, although I should certainly not recommend it in this country, in which good water limes are too common, to render it worth while to make artificial ones, and too valuable to be used as ingredients for an artificial water cement.*

In order to ascertain the best mode of forming an artificial cement, with any hard stone consisting of pure carbonate of lime, such as white marble, and clay, we used the quick lime of chalk, which is the same as the quick lime of white marble; but as chalk broken into irregular lumps could not be measured with any degree of accuracy, we had recourse to weight, for determining the proper proportions of the lime and clay, in the peculiar experiments now under consideration.

After due investigation, we found that any given weight of well burned chalk lime, and consequently of any other pure quick lime fresh from the kiln, combined with twice its own weight of blue clay fresh from the river, will form an excellent water cement, observing however, that the quick lime after being weighed must be slaked with excess of water into a thinnish paste, and allowed to remain in that state about 24 hours before it is mixed with the clay. These proportions by weight are as nearly as possible equivalent to a mixture of 5 measures of chalk powder to 2¼ measures of blue clay, absolute identity of proportion not being necessary, as was explained in Article 83, and it being always desirable, to avoid fractions, whether measure or weight be used for proportioning the ingredients of an artificial cement.*

---

* Such was my opinion some years ago, but Mr. Richard Greaves, of Stratford-upon-Avon, proprietor of blue lias lime works, has recently been in the habit of manufacturing part of his lime into an artificial lias cement, according to the rules laid down in the first edition of this book, as he told me when I met him by accident.

(97) *The slaked Water Limes, or slaked Hydraulic Limes, and Clay.*

To make a water cement, by a mixture of the slaked water limes and clay, the same process must be followed, by burning the lime first, weighing it in the state of quick lime fresh from the kiln, slaking it with excess of water for 24 hours, and then mixing it with blue clay fresh from the river.

But in respect to the proper proportional weights, as all the water limes contain a certain proportion of clay in their composition, whilst the pure limes contain none, a given weight of the former when burned into quick lime must not be mixed with double its own weight of blue clay, which is proper in working with chalk or other pure lime, but with a smaller proportion.

Thus, for example, we found that any given weight of the blue lias quick lime, when mixed with an equal weight of blue clay, the former fresh from the kiln, the latter fresh from the river, made a good water cement.

To produce the same effect, with other hydraulic limes, each of these respectively must be mixed with a different proportion of clay, according to its own peculiar quality. Thus, for example, a given weight of Dorking lime fresh from the kiln would require more than its own weight, but less than twice its own weight, of blue clay, to make a good water cement, this lime being in an intermediate state between the blue lias lime, to which the former, and chalk lime, to which the latter of those proportions is suitable.

(98) *Lime and Clay burned separately.* Having burned chalk lime and clay separately, and mixed them together into balls with water, after previously pounding them, I never could succeed in obtaining a good artificial cement by this method, as the balls always went to pieces on immediate immersion.

Yet as the expedient of mixing pounded tile-dust with lime has been used in the Mediterranean for the lining of cisterns, whenever puzzolana could not be procured, even since the time of the Romans, I have no doubt, that the mixture of slaked quick lime and of calcined clay, which has been adopted and strongly recommended by General Treussart in France, may be very useful for many purposes in Hydraulic Architecture, although much inferior not only to the natural, but to most of the artificial cements produced in the course of my experiments.

---

* 555 grains of quick lime are the produce of 1000 grains of dry chalk, which in the state of powder will fill 5 measures, of which 1110 grains of blue clay, being double of the first-named weight, will fill 2¼.

(99) *Of the additional substances by which the best natural Water Cements may be spoiled.*

It having occurred to me that it might be desirable to ascertain what ingredients would injure or ruin the best natural cements, as it appeared probable that the same might produce a like unfavourable effect upon artificial mixtures used as substitutes for them, the following experiments were tried.

Sheppy Cement mixed with Charcoal or Linseed Oil.

Having pulverized the Sheppy cement and mixed it up into balls with a proportion of pounded charcoal or of linseed oil, these ingredients did it no injury. In fact, as they were burned out during calcination, they only served as fewel to promote this process.

(100) But we found that oil or grease of any kind has a most injurious effect on cement powder, if mixed with it, not before but after it has been burned; for they converted it into a pulpy mass that would not set at all.

Having mixed the calcined Sheppy cement powder with salt water, and also immersed the balls thus formed in salt water soon afterwards, they appeared to set nearly as well as if fresh water had been used, but threw out a much greater efflorescence from the surface.

(101) *The Sheppy Cement and the Carbonate of Potassa.*
The Sheppy Cement and the Carbonate of Soda.
The Sheppy Cement and the Muriate of Soda.

Having pulverized the Sheppy cement stone, and mixed it successively with the above-mentioned alkaline salts in various proportions, and burned each mixture, we found that the cement could bear a proportion of nearly one-third without being much deteriorated, but not more. Hence as salt is certainly unfavourable, I would never mix cement with salt water, except in case of absolute necessity.

(102) *Chalk, stale alluvial Clay, and the Alkaline Salts.* Before I became aware of the great quantity of hydrogen gas contained in fresh alluvial clay, having ascertained during my repeated washings of the blue clay before alluded to (90)

that the clear water drawn off contained no iron, but was impregnated with alkaline matter, I was induced to mix well washed and consequently stale alluvial clay with chalk in the usual proportion, of 5 measures of the latter to 2 of the former, adding small proportions of the carbonates of soda and of potassa, and of the muriate of soda, all of which appeared at first to produce a most favourable effect, but eventually failed.

(103) *Chalk, Pipe Clay, and the Alkaline Salts.* To pursue the same investigation, previously to the failure of the last-mentioned mixtures, I added a proportion of the same alkaline salts to the usual cement mixture of 5 parts of chalk and 2 of pipe clay, and all of them yielded artificial cements that set immediately under water in a most promising manner; but in the course of a period not exceeding from six to ten or twelve days, most of them cracked at the surface, and the inside of them proved unsound. Some few, especially those in which the salt was not more than one-fiftieth part of the whole compound, remained good, and proved in breaking them to be hard inside, but these mixtures are too precarious to be depended upon.

THAT SALT IS VERY PREJUDICIAL TO BRICK EARTH.

(104) A curious circumstance was observed in the experiments now alluded to. Our former mixtures of chalk and pipe clay had always burned into a kind of brick much harder than any of our other calcined compounds. The smallest addition of the muriate of soda to the same mixture completely deprived it of its plasticity, and caused it to burn into a soft friable mass, capable of being rubbed to pieces by the fingers.

This experiment, and those relating to fullers' earth, recorded in Article 95, combine in proving, how very injurious a proportion of salt must be to the earth used in brickmaking.

(105) *The Sheppy Cement and the Carbonate of Magnesia.* The carbonate of magnesia being the only substance that did not injure the Sheppy cement, when mixed with it in a greater proportion than one-third, and treated as in Articles 99 and 101, we increased the dose of magnesia gradually, and finding that an equal quantity of magnesia did not injure the cement, we tried two measures and afterwards three measures of magnesia to one of cement; and even this great excess of the former ingredient did not deprive the latter of its virtue as a water cement.

THAT MAGNESIA IS A WATER CEMENT.

(106) From this unexpected circumstance I was induced to try magnesia alone, unmixed with any other substance, and having burned the carbonate of magnesia, and made the calcined powder into a ball with water, it gave out no perceptible heat, but at the end of twelve hours, when it had become hard, I put it into a basin of water, and it continued to set in that fluid. On mixing Henry's calcined magnesia, which of course required no burning, with water, and forming it into balls, the same effect took place. Thus the curious fact developed itself, that pure magnesia is in itself a water cement, but a slow setting one, for it did not succeed on immediate immersion.

THAT THE ARTIFICIAL CEMENTS ABOVE DESCRIBED ARE CAPABLE OF RESISTING THE SEVEREST FROSTS.

(107) In the very severe winter of 1829-30, having previously prepared a great number of the experimental cement balls described in the foregoing Articles, I exposed them on the top of a porch for about a fortnight in January, 1830, and as a good deal of snow fell which would have protected them if left there unmoved, I took them down every morning, laid them before a fire until they were quite warm, immersed them in a basin of water for about half an hour, and then replaced them on the porch, previously sweeping off the snow if any had fallen during the preceding period. All the artificial cement balls, which had been approved by us before, stood this severe test quite as well as the Harwich and Sheppy cement balls, which I also exposed in the same manner. In fact the frost did no injury to any of them.

I have however observed that frost injures the best cement, whether natural or artificial, if laid on as stucco in an injudicious manner, which, if the proper mode of applying it be understood, any workman can effectually guard against. This point will be explained hereafter.

OF THE EXPERIMENTS ON A GREATER SCALE WITH KILN-BURNED ARTIFICIAL CEMENT. THAT OUR FIRST ATTEMPT IN 1829 FAILED, OWING TO THE RAW MIXTURE HAVING BEEN SPOILED BY WASHING IT.

(108) Having, towards the close of the year 1828 and in the beginning of 1829, tried as many experiments on a small scale as I then considered necessary, I determined to prepare a considerable quantity of artificial cement composed

of chalk and blue clay, with a view of applying it on a larger scale, to those purposes for which the natural cements have been used in Architecture.

The chalk, after having been broken small and dried in the air, was pounded in small quantities at a time, in iron troughs that had belonged to a forge, with iron rammers made for the purpose, and was passed through sieves with brass wires, having 25 meshes to the inch, being the finest used in the Ordnance gunpowder works. A large mass of dry pulverized chalk being thus provided, 5 cubic feet of it were laid on a wooden platform, and made into a paste with a moderate quantity of water, after which 2 cubic feet of the blue clay were added, and the whole intimately mixed together on the same platform by shovels. When a sufficient quantity was prepared, the mixture was next moulded in the same manner as common bricks, excepting that water was used instead of fine sand to prevent adhesion. After these bricks of raw cement, which were 12 inches long, became drier, they were cut into five equal parts, each forming a cube of rather less than 2½ inches side, this being the average size of the lumps into which chalk is usually broken, before it is burned, in the common open lime-kilns in Kent.*

(109) Having prepared a considerable quantity of these raw cement cubes, on burning a few of them in a fire-place before I sent them to the kiln, the calcined cement seemed rather inferior to that obtained from my former experiments, and on examining the remainder of it, it appeared that the workmen had not taken sufficient pains in making and mixing it, the cubes being coarse-grained and porous, and having the dark colour of the inside mottled with specks of white chalk. I therefore threw the whole of this mixture away, and to remedy these imperfections I determined to adopt the process of washing, which is known to break down all clays, and which is therefore always used in the preparation of mixed brick earths previously to moulding. I caused the blue clay to be squeezed through a coarse sieve, to remove pieces of vegetable matter, with which it was occasionally adulterated, and ordered the chalk, after having been pounded and sifted as before, to be ground still finer in an iron mill that had been used for grinding linseed. After the ingredients thus prepared had been well mixed in the

---

* I made my moulds exactly 12 inches long, and $2\frac{4}{10}$ inches wide by $2\frac{4}{10}$ inches deep, in order that 25 bricks, or 125 cubes, should be exactly equal to one cubic foot. Thus, by merely counting the number of bricks, we could ascertain the quantity of raw cement made, without the trouble of measuring it.

due proportion, the compound was put into a large tub, with about twice its bulk of water, and the whole was well stirred, after which the mixture was allowed to subside, and the clear water from the top was drawn off by a syphon. More water was then added, and the same process repeated for about ten days. After the water was last drawn off, care was taken to remix the ingredients well, lest the heavier parts of the original mixture, from having been so often held in suspension and deposited again as a sediment, should have got to the bottom. The mixture was then moulded and cut into small cubes, in the manner before described, which being well beaten with little wooden bats, whilst moist, were thereby reduced to somewhat less than their original size. These cubes of raw cement, when dry, were extremely sound and of homogeneous colour and texture, so that I expected that they would now make a perfect cement; instead of which, I was surprised and disappointed to find, on again burning a few for trial, before I sent the whole quantity to the kiln, that the calcined cement obtained from them would not harden at all under water, but remained in a soft pulpy state altogether unfit for the purpose in view.

In consequence of this circumstance, which was before mentioned in Article 90, I gave up all further proceedings for that year, it being rather late in the season, and renewed my crucible experiments, in hopes of discovering the cause of this unexpected failure, together with the means of avoiding it for the future, which occupied me for the remainder of that year and part of the next; but having already recorded the whole of my experiments on a small scale, whether tried before or after the period alluded to, it is unnecessary to repeat them here.

SECOND FAILURE IN 1830, OWING TO THE RAW CEMENT MIXTURE HAVING BEEN SPOILED BY TOO LONG EXPOSURE TO AIR.

(110) About the beginning of March, 1830, having finished the preliminary experiments alluded to, I reverted to my original intention of preparing a sufficient quantity of artificial cement to operate with on a large scale, and as an addition of coal-dust had in some of my crucible experiments (87) cured the raw cement mixtures that had been spoiled by excess of washing, it appeared reasonable to suppose, that this ingredient introduced into the original mixture might prevent that evil. I therefore prepared a considerable quantity of raw cement, composed of a mixture of 5 measures of chalk,

2 measures of blue clay, and half a measure of fine coal-dust. The dust was obtained by pounding small coals in the iron trough, and was mixed with the pounded chalk dry, and the two were ground together in the oil-mill before mentioned. They were then mixed up with water on the wooden platform, and lastly the clay was added, which had only been squeezed through a sieve without washing, and the whole of the ingredients were intimately mixed by the shovel.

Some of the cubes thus prepared, being burned for trial in a common fire-place, yielded a very good cement; but instead of sending the remainder of my raw cement immediately to the kiln, I thought it expedient first to ascertain, by experiment, how long the calcined cement would keep if exposed to the air of a dry apartment, before it lost its virtue, and whether it would keep better in calcined cubes or in powder. In experimenting upon this subject, I made up successive portions of my calcined cement powder into balls with water once a week, and found that as it gradually became staler, these balls were less perfect at each trial; but they were not so much injured during the first two or three weeks as to be unfit for use. Afterwards they deteriorated more rapidly, till they became at last completely unserviceable, and would not set under water at all.* The same calcined mixture remained much longer perfect in the form of cubes, but there are strong objections to this mode of preserving cement (49).

Two months elapsed before this experiment, which I did not wish to hurry, was brought to a conclusion, after which, reserving only a few more cubes, I sent the remainder of the raw cement, made at the commencement of this period, and amounting to more than 20 cubic feet, to a lime-kiln in Chatham, where a very intelligent foreman, after spoiling a few of the cubes put in for trial, burned the remainder of it remarkably well, by using a smaller proportion of coals than he had been in the habit of using for burning chalk. The fewel and the cement cubes were laid according to custom in alternate layers, in this kiln, which was of the common form of an inverted cone open at top; but as the quantity sent by me was not sufficient to fill the whole kiln, the cement cubes were placed in the centre of it, with chalk above and below them.

(111) Having satisfied myself that the cement thus made was burned to a nicety, I caused it to be pounded in the iron

---

* The calcined cement powder experimented upon was kept in a shallow dish. Cement powder kept in an air-tight cask, or other deep vessel open at top, would be much longer in spoiling, because the upper surface for a couple of inches down, though injured itself, would protect the remainder of the mass below from the action of the air.

due prop
with abo
stirred, af
the clear
More wat
for about t
was taken
parts of th
in suspens
got to the
into smal
being well
thereby r
These cub
and of ho
that they
which, I
burning a
the kiln, t
not harde
state alto
In con
mentione
that year,
crucible c
this unex
it for the
year and
whole of
before or
repeat th

SECOND
MIXTU
SURE

(110) A
the preli
original in
cement to
coal-dust
the raw c
washing,
dient intr
evil. I t
cement,

me the use of a small lime-kiln about 4 feet in diameter at top, and 6 feet deep, which he had chiefly built for experimental purposes. In this little kiln, than which nothing could have answered better, we burned, at four successive periods of the same year, about 140 cubic feet of raw cement. In the first of these batches of artificial cement we used the same mixture as before of 5 measures of chalk, 2 measures of blue clay, and half a measure of coal-dust; and in burning it, after putting in shavings and wood at the bottom of the kiln, we laid half a bushel of coals over the wood, then four bushels of the raw cubes, after which another layer of half a bushel of coals, then four bushels of cubes as before, and thus we continued applying the coals and cement cubes in alternate layers, until the kiln was filled, using one measure of coals to eight measures of raw cement, the former being broken rather small, so that no piece of coal used exceeded an inch in thickness, and both being thrown loosely into the baskets with which we measured them.

The cement thus obtained was certainly underburned, as it effervesced in acids more than was desirable, but finding that it hardened under water, I determined to use it, although I considered it from the above circumstance to be of an inferior quality. I therefore built a small brick tank in the garden attached to the Field Officer's quarter occupied by me in Brompton Barracks, Chatham, and plastered the inside of it with the cement that has just been described, which was applied net about three-quarters of an inch thick, and was well worked in and compressed, and brought to a very smooth surface by the trowel. The tank was then covered over by a flat brick arch laid in cement, with a manhole in the centre; and a small brick drain was formed to convey the rain water to it from a roof, and another to carry off the waste water, if it should rise nearly to the spring of the arch, which drains also were laid in the same cement. In the rough brickwork of the body of the tank, instead of common lime mortar, I used the inferior cement previously burned in the kiln at Chatham (111) mixed with sand, and which, although quite unfit for the more delicate purposes of a water cement, seemed to be in the same state nearly as the blue lias or Dorking limes, and therefore superior to common lime for all hydraulic purposes. A fortnight after the plastering of the tank was finished I caused it to be filled with water, when it proved perfectly water-tight.

(113) In the second batch of cement, burned at Gillingham, we used the same mixture of chalk, blue clay, and coal-

dust, as before; but increased the proportion of coals or fewel, by using one measure of coals to seven only of the raw cement cubes. Afterwards we found that about one of the former to seven and a half of the latter was sufficient for this peculiar mixture.

In the third and fourth batches of raw cement prepared for burning at the same kiln, we dispensed with the coal-dust altogether, using 5 measures of chalk to 2 of blue clay; and we merely pounded and sifted the chalk, without grinding the powder afterwards in the mill; and in consequence of there being no fewel combined with the raw cement in this mixture, we used one measure of coals to five measures of the raw cement cubes in burning them, which proportion we always adhered to afterwards, as the best for this mixture; but if we could have kept the little kiln constantly burning, as is often the case in lime works, by adding more fewel and cubes at top from time to time, in proportion to the quantities drawn from below, a smaller proportion of coals than one-fifth would have sufficed, after the first portion of calcined cement should have been drawn; and it may be observed also, that whether kept constantly burning or not, a larger kiln would probably have required less fewel under the like circumstances.

The two last-mentioned batches of artificial cement proved to be the best of any of the kiln-burned cements that we had yet made; and the previous process of mixing was much simpler and cheaper than when coal-dust was used; notwithstanding which, the results of some crucible experiments tried the same year induced me afterwards to return to the use of coal-dust, which I did not finally abandon, until more conclusive evidence convinced me that it was not advisable to use it at all (89).*

(114) In 1831 we burned seven batches, and in 1832 five batches more, averaging about 35 cubic feet of artificial cement each, the whole of which has been applied to practical purposes. The mode of proceeding finally adopted was this. In preparing our artificial cement for the kiln, we had the chalk powder all ready for mixing, before we brought up the clay from the river, in order that the latter might be used quite fresh. Generally from 10 to 12, and never exceeding

* As I had only three or four soldiers employed in preparing my artificial cement, who could not work constantly, owing to the military duties of which they had to take their share, it required about a month to prepare each portion of about 35 cubic feet for the kiln. Hence we were only able to prepare six batches of artificial cement, including the two burned in Chatham, in 1830, before the early frosts of that year set in.

14 days, were allowed to elapse between the moulding and the burning of the artificial cement, for the purpose of drying the cubes,* which were not injured by this delay, though from the principle before explained, if they had been made much smaller, as for example only one inch each side, they would have been completely spoiled in a much shorter period (86).

After lighting the kiln, we generally allowed 24 hours to elapse before it was drawn, or sometimes more, in order to give our cubes time to cool, for although they were sufficiently burned in a shorter time, we found that they were liable to break or crumble to pieces when handled, if taken out of the kiln warm.

(115) It is proper to observe, that one of the batches of artificial cement burned in 1831 proved defective, inasmuch as it would not set under water, and when afterwards used as stucco, it cracked much more than any of our former specimens had done. This was the first batch of artificial cement made without the presence of my intelligent assistant James Menzies, he having been ill at the time, which circumstance was very discouraging to me, as success seemed to depend upon one individual; for the men who made it declared that they had followed the same proportions and mode of proceeding that he had done, in every respect. Afterwards on interrogating them more strictly, the cause of failure was discovered. The man who served out the pulverized chalk had compressed it in the measure as closely as he could, so that he had forced a much greater quantity into the same space than had ever been used before; and thus, as the blue clay in its moist state is incompressible, the true proportion used in this mixture was 7½ measures of chalk powder to 2 of blue clay, which is proper for a water lime, but not for a water cement (83), and to which, if we had known it at the time, we would have added more sand as being a lime stucco (56).

(116) In the first batch of cement made in 1832, we used a fine brown pit clay from the vicinity of Upnor, which had previously been employed by Mr. Frost in his artificial cement works. As this was much drier and more compact than the blue alluvial clay, we mixed it with water till it was brought to the same moist state as the latter, after which we mixed it with chalk in the same proportion. This also made a good artificial cement, but had the disadvantage before alluded to

---

* We dried one batch of our raw cement in a couple of days by laying the cubes on iron plates over a fire.

of being a great deal harder than the blue clay mixture after calcination (92), and the stucco made from it also cracked more than that formed of the latter. Hence we did not use the brown clay a second time, it being evidently inferior to the blue.

Besides finishing the garden tank before mentioned, and stuccoing and coping a dwarf brick wall by which it was inclosed, the remainder of our kiln-burned artificial cement of 1830, and the whole of that burned in 1831 and 1832, were applied to practical purposes at or near Brompton Barracks, as was before mentioned (3).

(117) Finding at the end of the first year that the stucco applied to the gateways, though generally of a handsome light brown colour, was not of the same tint throughout, some parts having become darker than others, we washed over the whole of our stucco with fluid cement, in order to obtain a more uniform colour, which expedient we adopted only from economy, as we considered oil colours, if not applied too soon, to be decidedly preferable for all such stuccos, whether made of natural or of artificial cement.

REMARKS ON THE KILN-BURNED ARTIFICIAL CEMENT, USED FOR THE PURPOSES OF PRACTICAL ARCHITECTURE IN 1830, AND THE TWO FOLLOWING YEARS.

(118) Many years having elapsed since our artificial cement was applied to all the purposes of Practical Architecture on a sufficiently great scale, we are now enabled to judge of its quality, which appears to rival that of the best cements of nature. The tank first made in the garden at Brompton Barracks has remained perfectly water-tight, and that near the married soldiers' cottages before mentioned (3) is in the same state, but the mode of filling the latter has proved unsatisfactory.* In plastering both of these tanks, net cement only

---

* The rain water from the adjacent road first flowed into a deep sesspool, from whence it passed over by a small covered drain, and fell into a filtering bed of gravel and fine sand, from which it ascended to a second drain of the same description, and then fell into the tank or reservoir. Owing to the exposed state of the road, this water was so very dirty that it soon choaked up the filtering bed. This arrangement was copied from the great military tank constructed by the late Major-General Forde, R.E., on the Western Heights, Dover, where it succeeded admirably, from being on a greater scale, and supplied with cleaner water from those heights. Having since examined the extensive filtering apparatus of the West London Water Works near Chelsea, constructed by Mr. Simpson, the Engineer of that Company, in which the water of the Thames, which after rains is exceedingly dirty, is filtered through a bed of sand and gravel by descent, falling from thence into apertures in small brick arches, from whence it issues remarkably clear, I am of opinion, that the same arrangement would have succeeded with our small tank, as filtering by descent seems to be better suited for muddy water, than by

was used; and wherever we formed cornices or other ornamental mouldings, or rusticated joints, net cement was also used at the outer surface, to the depth of a quarter of an inch, or sometimes more; because we found that cement mixed with sand was not capable of producing such *sharp arrises*, technically speaking, or, in other words, such well defined angles, as we desired.

Most of our cement chimney-pots were also composed of net cement at the surface, for although formed of small fragments of tiles and cement powder mixed with water, well stirred up together and poured into the mould, we found that the pieces of tile usually got towards the centre, being seldom within a quarter of an inch of any of the sides of the mould; whence the fluid cement, though it effectually pervaded the whole space, was in greater mass at the sides than any where else. Our cement copings, likewise formed in a mould, being made of net cement and fragments of tiles, not always cast fluid, but sometimes worked together by the trowel and by the hands, had also the top and sides of each piece of coping formed of net cement, to the depth or thickness of about half an inch from the surface, or sometimes more. Those artificial coping stones were all set in net cement.

(119) In respect to our artificial cement stucco, as applied to plane surfaces, having little experience in the use of cement at that time, I thought it desirable to try several sorts; and accordingly in some of the gateways, I used two measures of cement powder to one of sand; in others equal measures of each; in others I directed one measure and a half of sand to be mixed with one of cement; and in others, two or three measures of sand to one of cement. The sand was all of good quality and sharp, but in some gateways we used it all very fine, in others all coarse, and in others coarse below and finer at the surface. In some few cases we laid on the stucco in two coats, sometimes scoring the surface of the first coat, and sometimes not; but generally we adopted what we found afterwards to be the most judicious system, of applying the stucco in one coat, not absolutely laid on all at once, but taking great care, after having applied a certain thickness over the brickwork, that the second or outer portion, whether of the same

---

ascent. Even at Chelsea, the several filtering beds require to be cleaned from time to time, by scraping off the upper surface of the fine sand, as soon as it becomes covered by and impregnated with a coat of mud, after the removal of which fresh sand is added.

or of a finer quality, should be laid on before the first had begun to set.

(120) Having recently cut out pieces of the cement copings before mentioned (118), and pieces of stucco, 2½ inches square, from each of the gateways down to the brick-work, we found that the net cement from the copings, in some parts nearly an inch in thickness, was exceedingly hard and sound. In respect to the stuccos of the gateways, varying from about five-eighths to one inch in thickness, we found that those, which had been formed of two measures of cement to one measure of fine sharp sand, were very good, being every where of the same hardness and compactness nearly as Bath stone; and a portion of stucco formed with equal measures of cement and fine sand was also good and sound, yet not quite equal to the former; but those stuccos, in which the proportion of fine sand by measure exceeded the cement, were hard at the surface only, all below being softer and weaker, where the fine sand was in moderate excess, and nearly as dry as dust, where it was in great excess.* But the best stucco of all was that which I know to have been formed of equal measures of coarse sand and of cement; and indeed all the stucco in which coarse sand was used proved to be good; but not having been present myself at the stuccoing of those gateways, where I had directed coarse sand to be used, in the proportion of two or three times the quantity of the cement powder with which it was to be mixed, I have great doubts whether the workmen did not adhere to the usual practice of plasterers, and use much less of the former ingredient than I had ordered; for I found in most of those men the greatest reluctance to deviate from their former habits, and in cutting into the portions of stucco now alluded to, the coarse sand did not appear any where to exceed the cement by more than one-half; and in one part in particular, where I had expressly ordered coarse sand to be used, we found nothing but very fine sand.

(121) In respect, however, to two gateways, where I had myself superintended the work in person, and for which I can therefore vouch, we found that the stucco of one, composed of 2 measures of cement to 1 of fine sand, which had been worked in and compressed with great care by one of the plasterers at my desire, was much better than the same kind of stucco, which had been applied by another plasterer,

---

* All stuccos, whether formed of a mixture of lime, or of cement, with sand and water, being worked up hard at the surface, it is impossible to judge of their quality, without cutting solid pieces entirely out in this manner, so as to ascertain whether they are equally hard throughout their whole thickness.

whom I allowed to work in the same hasty manner that he had previously been accustomed to, before he entered the Corps. The former stucco was of equal hardness and compactness throughout, and showed no cracks for nearly a year after it was applied, and on examining these cracks at the end of several years, they proved to be merely hair cracks, not extending more than the 50th part of an inch, and I have even doubts whether they penetrated much deeper than the cement wash used for colouring the stucco (117).*

Some very small portions of our artificial cement were injured by frost, owing to our inexperience in the mode of applying it, but we soon discovered the peculiar circumstances under which this takes place, which are easily guarded against, and which I shall now proceed to explain.

RULES FOR PREVENTING CEMENT IN OUTSIDE WORK FROM DETACHING ITSELF, ESPECIALLY AFTER FROSTS.

(122) New brickwork intended to be coated with cement-stucco is left rough on purpose, but when old brickwork is to be stuccod, the mortar must be raked out of the joints for about an inch deep, and roughened, and the bricks scored by a light axe, and the surface of the wall should be perfectly clean (100), for which reason, if blackened by city-smoke, or otherwise greasy, it should be scraped as well as scored, and well moistened, or rather wetted with water, before the stucco is applied. It is also desirable that more labour should be given to this process than is usual in England, where the plasterer, instead of compressing the whole of the stucco, lays on the body of it in haste and very loosely, and then waits till it is on the point of setting, after which he works up the surface only, with a smaller proportion of finer sand, and thus produces a hard but thin crust over a coarse porous substance.

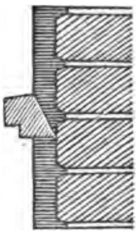
---

* The gateway at the N. W. angle of the Barrack Square leading from the Officers' quarters to the North Stable yard, and the outer gateway of that yard, were stuccod with 2 measures of cement powder mixed with 1 measure of fine sand. The gateway at the N. E. angle of the Barrack Square was stuccod with equal measures of cement and of coarse sand. The Eastern wing wall outside of the Principal Gate leading into Brompton at the S. W. angle of the Square, was stuccod with a mixture of very fine sand and cement, the sand being in excess. The convex back wall of the entrance leading from that gate to the South stable yard was stuccod with 1¼ measure of sand to 1 measure of the inferior cement mentioned in Articles 110 and 111. These two last-mentioned are the only bad or indifferent stuccos out of the whole. All the others are good, and some excellent. The artificial cement made of the brown pit clay from Upnor was used in stuccoing the rustic piers of the garden gate behind the centre of the Officers' quarters, but not for the ornamental cercophagi over those piers, which were made of the blue alluvial clay, and which are the finest specimens of our artificial cement.

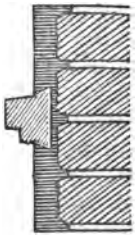
(123) The only precaution necessary to prevent cement, whether pure or mixed with sand, from being injured by frost, is never to allow any part of it to set completely before a second coat is applied, for in this case the joint between two such coats is always a weak part, and if water penetrates into it, will be sure to give way if attacked soon after by frost. In stucco applied to the face of a wall, this defect may not come into notice, because the rain generally falls off without penetrating quite so deep as the vertical joint between the outer and inner coat, and at top such joints are always protected by a projecting cornice or coping, as was the case in our gateways. Hence we did not discover the weakness of any of those joints until we cut into them at the end of five or six years, as was before mentioned (120), when the two coats immediately separated, as soon as the chisel reached the inner one, showing that they had not had any effectual adhesion; but in respect to part of our cement coping, not previously made in pieces in a mould, but formed by the plasterer on the wall itself with fragments of brick, and with cement-stucco laid on in several coats, the weakness of the joints between those successive coats became apparent in a few weeks after the work was executed, which was rather late in the year; for the rain water having penetrated into those joints which were near the surface, and freezing afterwards, broke off the upper coats, which were very thin, one after another.

The same effect occurred in respect to a small ornamental column, from the base of which a torus or semicircular moulding detached itself, and also in respect to the first gateway of the Barracks stuccod by us, from which part of an ornamental fillet separated, after the first hard frosts of the same season. The torus and fillet, in both cases, projected from the surface of the first coat of stucco, and the joints connecting them to it were nearly vertical and exposed at top, so that the water naturally descended into those joints where it lodged itself, and when frozen broke off those little ornaments, but only partially. In short, though several severe winters have occurred since, no injury has been done by the frost to any of our artificial cement, except under those circumstances, of its having been applied in two coats, and with the joint injudiciously formed and exposed. In those cases, we observed that the corresponding surfaces of the first coat, which was still adhering to the wall, and of the second coat, which had detached itself, were perfect, for the plasterer had in all of them scored the former well, expecting that this precaution would make the second adhere to it; and the marks upon the two surfaces which had been in contact, concave on the one and convex on the other, corresponded as exactly as the coin does to the die, by which it has been stamped. Thus cement sets too quickly to admit of its being laid on in two coats, like common plasterers' work of lime mortar. If applied in two thicknesses, the second must be laid on almost immediately, and long before the first has begun to set, so that properly speaking these two thicknesses form only one coat.

(124) In respect to our cement chimney-pots cast in moulds as before mentioned, and to such of our artificial coping stones, as they may be termed, which were formed in moulds, no part of the cement used in either having been allowed to set partially, and consequently there being no internal joint, or weak part, they have all stood the severest winters to which they have since been exposed without the smallest injury.*



(125) The fillet before mentioned, which partially detached itself, had been added to the surface of our cement-stucco, after previously cutting a triangular groove to receive it, which, having the base of the triangle at bottom, as shown in the first of the annexed figures, allowed the water to descend into the joint. If this triangular section had been reversed by having the base uppermost, this defect could scarcely have taken place.



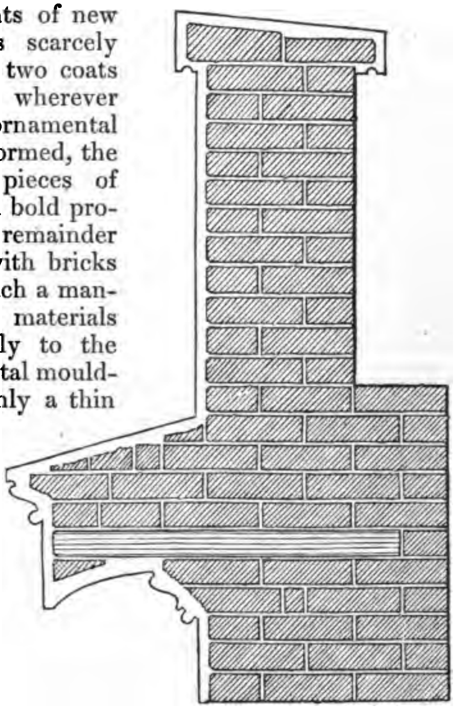
To remedy it, I caused the whole of this fillet to be cut off, and the triangular groove enlarged until it assumed a dovetailed form, as shown in the second figure annexed, thus obtaining what plasterers technically term *a key,* which has the same power as a dovetail to prevent separation.

(126) On inquiry, the best plasterers have since assured me, that the joint between two coats of cement is always weak, and that the same little failures which I experienced would have taken place with the best natural cements, and therefore they always avoid using two coats of cement-work if possible; but should that be absolutely necessary, they take extraordinary precautions

---

* Some of the cement chimney-pots have since been removed, on account of the aperture, which was only 7 inches square in the clear at top, being rather too small for the fire-places, especially those used as kitchens. We were not aware, when we made our mould for casting them, that this size would prove objectionable. Nine inches would have been sufficient.

to obtain that sort of key which will prevent the second from separating from the first.



In the cement fronts of new brick buildings, it is scarcely ever necessary to use two coats of cement, because wherever cornices or other ornamental mouldings are to be formed, the architect introduces pieces of Yorkshire stone for all bold projections, making up the remainder of those projections with bricks cut, if necessary, in such a manner, that these rough materials approximate so nearly to the outline of the ornamental mouldings proposed, that only a thin external application of cement is necessary for the finishing, which may every where be laid on in one single coat, according to rule. The annexed figure shows the facility with which this object may be effected, being the section of a cornice and parapet, such as might be used for a first-rate house in London. One course of Yorkshire stone, having small pieces of cut bricks supposed to be attached to its lower surface by net cement, supports the whole projecting part of the cornice, the rest of which is formed of common bricks, whilst the coping of the parapet above is formed partly of bricks on edge and partly of bricks laid flat or in their usual position. The joints of the brickwork are shown, whilst the coating of cement afterwards to be applied, nowhere much exceeding an inch in thickness, has its outline also distinctly defined, and is left unshaded.

(127) Where woodwork is used to obtain such projections, which is not so good an arrangement as the former, but often practised in common dwelling-houses as being cheaper, it is proper to fix battens to the surface of the wood, and over them laths, in order to obtain a proper key for the cement.

(128) In forming circular projections of cement of moderate

relief over brickwork, it is usual to drive large nails, and to connect them by pieces of spun yarn or rope yarn passing round and between them in zigzags, the whole of which being covered by and imbedded in the cement afterwards applied, prevents it from detaching itself. In this manner we prepared for the semicircular architraves over the doors of our brick sentry boxes, near the principal gate of Brompton Barracks, driving long nails into the joints of the brickwork before it was stuccod, which, having spun yarn passed round them afterwards, in the manner described, have effectually secured those mouldings, which project further than the rest of the stucco, and were laid on as a second coat.

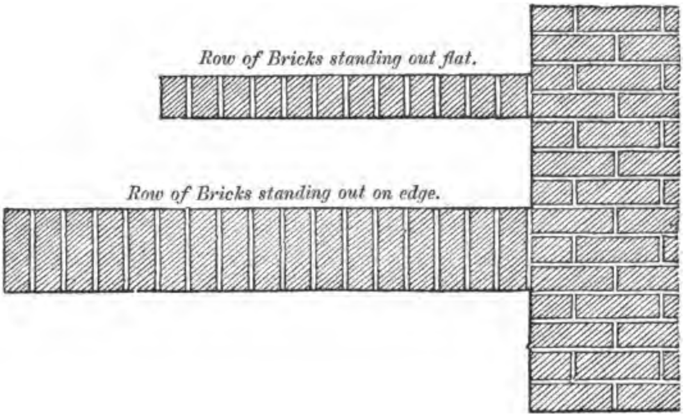
(129) Circular cement mouldings, not attached to a plane surface, such as the bases and capitals of columns, are often cast in moulds, in two or more pieces, and fixed by net cement, round the rough shaft previously formed of brickwork. When we consider the prodigious strength given to projecting cement-work by Mr. Brunel's ingenious arrangement of hoop iron, before described (59), there could be no difficulty in forming the boldest projections with bricks and cement alone, aided by iron, supposing that Yorkshire stones, or other stones of a similar description, or rough slates of inferior value, suitable for this purpose, could not be procured. For it is well known that a row of single bricks may be made to stand out from the plane surface of a vertical wall by cement alone; and although such rows of bricks are so far weak, that if you go on increasing their number, and consequently the length of the projection, beyond a certain limit, they will break off near the wall by their own weight, yet the length to which they may be carried out without this risk far exceeds that of the Architectural Projections usual for the largest edifices. Hence, as I said before, the aid of iron would render projecting bricks laid in net cement perfectly safe and efficient, that is, under the rather improbable hypothesis, also before stated, of a deficiency of more appropriate materials.

(130) Moreover, bricks connected by net cement may previously be formed into masses, or artificial stones, in order to save time in placing them in tide-work or in drains; and for the latter purpose they may have the arch-like form, which expedient has been adopted in Chatham Dockyard; but as the various modes of using cements in general have now been noticed, as far as appeared necessary, I shall enlarge no further upon this subject, but return to our own proceedings.

EXPERIMENTS PROVING THE STRENGTH OF OUR ARTIFICIAL KILN-BURNED CEMENT.

(131) The Master-General and Board of Ordnance having directed the arched roofs of some of the casemates in Chatham Lines to be plastered with Harwich cement, in 1830, to prevent the rain water from filtering through and destroying the mortar, Captain Streatfield, the Engineer Officer in charge of that work, borrowed some of our artificial cement from curiosity, in order to compare it with the Harwich cement about to be used there, which he considered to be of good quality. In trying the strength of each, a brick placed horizontally in the direction of its length, was attached by means of net cement applied to one side of it, to the vertical surface of the wall of one of the casemates, the cement being well compressed in applying the brick, which was steadied for about two or three minutes by holding the point of the trowel firmly against it. The bricklayer then left it, until he had mixed up as much net cement with water as was necessary for the next joint, after which he applied another brick; and the cement set so quickly that the time required for placing each brick did not average more than six or seven minutes; and thus he proceeded, adding one brick to another until the mass gave way. Not being present myself at all these experiments, I was informed by the foreman of bricklayers, that he considered my artificial cement to be rather stronger than the Harwich cement, with which it had been thus compared; for both of them had supported ten or eleven bricks before the joints gave way, but that the artificial cement had supported the greater number more frequently. I was myself present at three experiments only. In the first, my artificial cement supported eleven bricks, but the joints gave way on the application of the twelfth. In the second, eight bricks were attached to the wall as before, after which 24 hours were allowed to elapse, and then four more were added, which composed a solid mass weighing 73¼ lbs., projecting 2 feet 11¼ inches from the wall, and nearly 9 inches in width, and 4½ inches in depth, as shown in the upper projecting row of bricks in the next figure, which is marked as *standing out flat.* On adding a thirteenth brick the mass broke down.

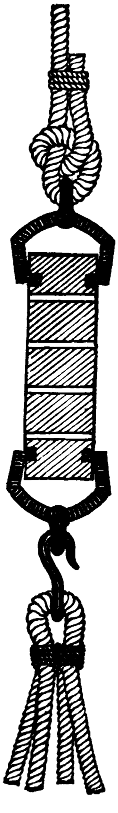
In the third experiment, eight bricks were attached to the wall one after another in the expeditious manner that has been described, after which one brick more was added daily, under an expectation that this system might render it possible to attach a greater number than before. This mass also broke down like the former, on the addition of a thirteenth brick. But none of these masses ever broke into more than two or three parts, and in the last experiment a portion of brick belonging to the original wall was torn out, instead of the cement joint giving way.


Row of Bricks standing out flat.
Row of Bricks standing out on edge.

(132) I was not aware at that time, that the more usual method in trying the strength of cement by attaching bricks to the upright surface of a wall, was to place them vertically in the direction of their length, forming a mass nearly 4½ inches in width and 9 inches in depth, as represented in the lower projecting row of bricks in the same figure, marked as *standing out on edge.* But supposing an equal number of bricks to be cemented together in both, in which case the quantity of solid matter projecting from the wall is equal, the second form, having double the depth, must be capable of supporting a much greater weight than the former; on the same principle as a piece of 4-inch plank, if placed flat and used as a beam by fixing it at one or both ends, will bend and break under a weight which it could support with perfect safety if placed on edge.

The Master Bricklayer in Chatham Dockyard informs me that he attached 14 bricks to a wall in this second manner, by cement which he considered to be of good quality, in which experiment he allowed a quarter of an hour for the placing of each brick and the setting of the cement joint, but that on adding a fifteenth brick the mass broke down. I suspect that this cement must have been rather stale, because Mr. John Hopkins, the Master Bricklayer of Woolwich Dockyard, to whom I made a reference, on hearing that he had tried similar experiments, informed me that in the course of several trials he once succeeded in sticking out 22 bricks from a wall by cement from the same manufacturers, which set so quickly that he was only obliged to allow 5 or 6 minutes in the placing of each brick, and it was not until the addition of a twenty-third brick that the mass broke down. In both Dockyards the cement supplied by other manufacturers, when tested in the same manner, proved inferior to the weakest of these two. Upon the whole I am persuaded that the average quality of approved cement supplied by the most respectable manufacturers will not stick out more than 18 or 20 bricks from a wall in this manner, although I admit that Sheppy cement of very superior quality and burned to a nicety, may, by using particular care in the mode of applying it, and by allowing of plenty of time, be made to support more. For example, I have myself seen a much greater number projecting thus at the cement works of Messrs. Francis, White, and Co., near Vauxhall Bridge, Lambeth, who assured me that they have repeatedly stuck out 29 bricks in this manner; and it was stated in my presence, at one of the meetings of the Institution of Civil Engineers, by Members of that Society, that so many as 30 bricks had been stuck out in one day, and 33 bricks in 33 days, in the same manner.

(133) Having proved its strength in the manner alluded to, we afterwards tried what weight was required to separate the joints of five bricks cemented together by our artificial cement, which we suspended vertically under an artillery gyn, or triangle used for mounting guns, by means of a pair of iron nippers clasping the sides of the upper brick, and having its claws let into mortises cut about three-quarters of an inch deep in the sides of the brick by a chisel. A similar pair of nippers reversed as to position clasped the lower brick in the same manner, to which was hooked on a large scale board for containing the weights, which were gradually increased until fracture took place. The annexed figure represents this apparatus, with the exception of the gyn and scale board, which would have occupied too much room, without making the description clearer.



In our first experiment we were obliged to put

1195 ℔s. into the scale, in order to tear the brickwork asunder; but as one brick only out of the five was separated in this first trial, we continued repeating the same experiment a second and a third time with the remainder of the mass, and it required successive weights of 955 and of 1099 ℔s. to produce fracture, in the last of which experiments one of the bricks was torn asunder instead of the cement joint giving way.

Trying the same experiment with another mass of four bricks connected by the same artificial cement, it required successive weights of 451 and of 1875 ℔s. to produce fracture; but on examining the first joint of cement that gave way, it was found imperfect, the two bricks that had been connected by it being united only at the edges, without having any cement in the middle.

As the bricks used in these last experiments were the same that had been attached to the wall of the casemate as before described (131), we concluded that if all the joints had been perfect, more than 12 might have been made to adhere to the wall. It did not occur to us to examine the joints at the time of our first experiments, which took place about four months before the last were tried.

We next tried similar masses of bricks that had been cemented by Harwich cement in the same manner, and we found it necessary in one trial to apply a weight of 1003 ℔s., and in another a weight of 1219 ℔s., to produce fracture. In another trial one of the joints separated without applying weights at all, during the process of cutting a mortise in one of the bricks to receive the nippers, but on examination this proved to be an imperfect joint without any cement in the centre, like that before described.

(134) Our next experiment was intended to ascertain the strength of our artificial cement, as applied to the joints of a brick arch. For this purpose we built a flat segment half-brick arch, that is, an arch of bricks placed horizontally in the direction of their length, having a span of 15 feet 4 inches, and a rise of only 9 inches, being less than one-twentieth part of the span, and the thickness of the arch according to this arrangement being not quite 4½ inches. The piers from which it sprang were 1 foot high and only 9 inches thick, but they abutted against the strong walls of one of the casemates; and these piers, as well as the arch itself, were each 18 inches or two bricks wide, measuring at right angles to the span of the arch. The first of the annexed figures is an elevation or longitudinal section, whilst the second is a plan of the top of this experimental arch, showing the manner

in which we thought it expedient to toothe the bricks of the arch, in order to break joint.

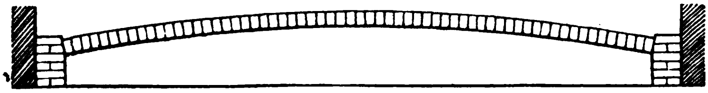


Fig. 1.

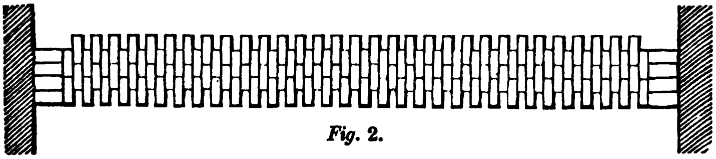


Fig. 2.

To try the strength of this arch, we loaded it four months after it had been built, with dry bricks laid over it in pairs, in the same manner in which the bricks of the arch itself had been placed, that is, horizontally in the direction of their length, and in successive courses of half a brick in depth or thickness, each course consisting of 138 bricks, and weighing probably about 640 lbs., which were all laid very loosely with wide vertical joints, and not in a compact mass, lest they should become jammed between the two walls, which would have defeated our object. No effect whatever was produced upon our arch, until ten courses of loose bricks, weighing 6400 lbs., were laid on, which caused a deflection of about 2 sixteenth parts of an inch. The 11th course caused a deflection of 3 sixteenths, the 12th of about 7 sixteenths, and the 13th of 10 sixteenths, but not long after the 14th course had been applied, at which time the total weight pressing on the arch amounted to about 8960 lbs., or to 4 tons,* it broke down with a tremendous crash, whilst we were about to measure the deflection. The third figure annexed represents the arch thus loaded with the 14 courses of loose bricks, which overwhelmed it in such a manner, that we could not ascertain in what point or points it gave way; but we observed, that the extreme brick had been broken at one end of the arch, for a fragment of this brick was found adhering to the skewback or oblique brick, forming part of the upper course of the pier on that side. In fact, such was the adhesive power of the cement, that the whole arch might be considered as a solid beam of brick, and it was broken

---

* We did not weigh the bricks used in this experiment, and therefore in naming 4 tons as the breaking weight, I have assumed an average of 4⅝ lbs. bricks, per brick, which is a good deal less than the average weight of bricks, which may be estimated at nearly 5 lbs.

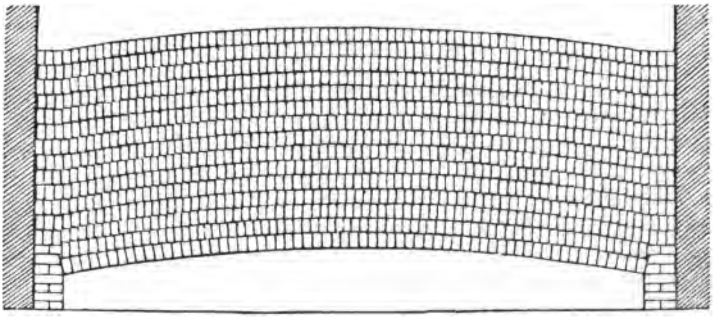


Fig. 3.

just as a beam of iron might have been fractured by excess of weight, gradually applied in the same manner.

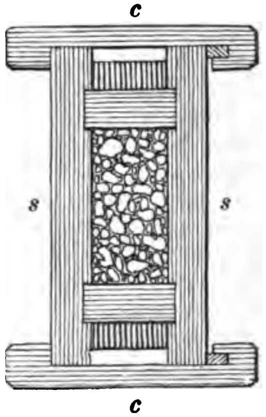
(135) We also built a similar brick arch with the best chalk lime mortar, immediately before we commenced the cement arch that has been described, using as a centering for both a mass of rammed earth, fashioned to the proper curved form, and resting on the floor of the casemate. We cut away the earth from underneath the cement arch the day after it was finished, but we allowed that of the mortar arch to remain during the whole period of four months before mentioned, after which we began to remove it, proposing afterwards to load this arch also in a similar manner, in order to compare the strength of our mortar joints and of our cement joints. But when we had cut away only a part of the earthen centering from under the mortar arch, it fell to pieces without giving us time to finish the removal of the whole of the earth, so that the mortar arch, though equally well built, proved incapable even of supporting its own weight.

(136) These results afford the most conclusive proofs of the expediency, or rather necessity, of using cement, not only in the brickwork of tunnels exposed to the action of water, such as the Thames Tunnel, but also in tunnels cut through much drier ground, such as those of railways; for it must be evident from these two experiments, that the pressure which a brick arch built with cement would be capable of resisting effectually, would crush a similar arch built with mortar, not merely if made of chalk lime, but of any other; for the best limes, even such as the blue lias, require a much longer time to set than the water cements, and until the joints of a tunnel become nearly as hard as the bricks themselves, it cannot be considered safe.

EXPERIMENTS ON A SMALL SCALE IN MAKING ARTIFICIAL STONE, OR CONCRETE.

(137) As the experiments tried on a small scale, both with the natural and artificial cements, proved so very satisfactory, and were such as enabled us with little trouble and expense to form an accurate judgment of the qualities of those useful substances, it occurred to me that it might be possible to judge in the same simple manner, how far any given sort of lime was fit for making good concrete (28), or good artificial stone on Mr. Ranger's principle (30).

With this view, early in the year 1836, I caused four wooden moulds to be made 4 inches long, 2 inches wide, and 2 inches deep in the clear, each consisting of two side pieces, *s s*, having grooves cut in them to receive two end pieces, which were fitted in very loosely to allow for the expansion of the wood, which was always to be used wet. The parts of this mould, which were about an inch thick, were held together by two clamps, *c c*, clasping the ends of the side pieces and tightened by wedges, the heads of which are seen in plan, in the annexed figure, which represents the mould put together, and supposed to be filled with concrete.



We provided also a number of thin pieces of board, about 8 inches long and 4½ inches broad, for temporary bottoms to these moulds, the ends of one of which are shown in the figure, upon which the small artificial stones made in them were left to dry for a day or two, and then placed on skids.

(138) Having prepared a mixture of sharp pit sand and small gravel, having no part larger than a horse-bean, we washed it well; and then sifted it, first through a screen with openings of one-eighth of an inch in the clear, all that would not pass through which was set aside as *Gravel.* The remainder being sifted a second time through a very fine wire sieve, having 30 meshes to the inch, was thereby divided into *Coarse Sand* and *Fine Sand.* The various sorts of limes experimented upon, all well burned and fresh from the kiln, were pounded in a mortar, and preserved in bottles filled

quite full and corked up, in order to exclude the air and prevent spontaneous slaking.

In these experiments we sometimes used only the gravel, sometimes only the coarse sand, and sometimes only the fine sand; at other times we used combinations of two of these, or of all three, in various proportions by measure, which we mixed up with each sort of quick-lime powder, also in various proportions, between 6 measures of silicious matter to 1 measure of lime, and 9 or 10 measures of the former to 1 of the latter. The limes used were chalk lime and Halling lime, both of the best quality, and three artificial hydraulic limes made by us, by mixing 5, 6, and 7 measures respectively, of chalk-lime powder with 1 measure of blue clay, on the principle before alluded to (83).

In making our concrete or artificial stones in these little moulds, after measuring the several ingredients, in a sufficient quantity of each mixture to fill two moulds, for we always made them in duplicates, we first mixed them up dry on a board, and then worked them up well, generally with boiling water, according to Mr. Ranger's principle, but occasionally with cold water, after which we threw the mixture in three or four portions into the mould, where it was carefully rammed, and finally the surface was stricken and worked up by a small wooden float.

In working with boiling water, after having used our four moulds successively, we found that by the time the fourth was filled, the concrete in the first had set sufficiently to admit of this mould being taken to pieces, which we did by taking out the small wedges, disengaging the clamps, and then the side pieces, and lastly the end pieces, one at a time. Having thus made our small artificial stones with the several natural and artificial limes above mentioned, we put them under water in a long tin trough, with cells, each containing one piece, in periods of not less than 16 nor more than 33 days afterwards; and we kept them immersed afterwards for about seven months, never changing the water entirely, but merely replacing the portion lost by evaporation.

(139) The results of these experiments seemed at first rather favourable to chalk lime, for all the concretes formed with it, in such very small moulds as have been described, had time to set before they were immersed, and as the water was never changed entirely, it had only a very moderate and slow action upon them (12), so that for several months after immersion, they seemed scarcely inferior to the con-

cretes made of Halling lime; but towards the close of the above-mentioned period of seven months, the inferiority of the chalk became apparent, for a mixture of chalk lime with rather more than three parts of fine sand, which we made in the same moulds, to represent chalk-lime mortar, and immersed after it had set to a certain degree, was friable and easily rubbed to pieces by the hands, and the concrete formed of 1 measure of chalk lime and 6 measures of gravel, proved to be in a state of pulp in all the joints, on being broken, and a considerable portion of the lime had quitted the joints, especially the external ones, from which it had almost entirely disappeared. The intermediate concretes between these two extremes, of chalk lime mixed with gravel alone, and with fine sand alone, were much better, but as the extremes both gave way, these experiments confirmed us in our former opinion, that chalk lime should never be used for concrete; because in such large masses as are required for the practical purposes of building, it would never have time to set in a damp situation, and wet would destroy it, of which I have known many instances. (See from Article 10 to 15 inclusive.)

(140) The concretes formed with the Halling lime seemed on the contrary to be rather improved by immersion, excepting one mixture only, which was formed of 1 measure of lime to 6 of gravel, which was the worst of all the concretes made with this lime, in like manner as a similar mixture was by far the worst of all those made with the chalk lime. In this mixture the Halling lime had partially quitted the outside joints of the artificial stone formed of it, but inside it was not soft or in a state of decomposition like the other. Of the other concretes formed with the Halling lime, and containing sand as well as gravel, those in which the fine sand rather predominated over the coarse were the best; and Halling lime mortar formed in the same mould, with 1 measure of lime to 3½ measures of fine sand, was excellent, it having improved very much after immersion. Hence these experiments confirmed the opinion before stated, that sand strengthens lime (42), for the only concrete of Halling lime which deteriorated under water was that before mentioned, in which the large joints which separated the particles of gravel consisted of lime paste or putty alone, unmixed with and unaided by sand, and were therefore weak.

These experiments confirmed another opinion also before stated (34), that good concrete cannot be made with any of the hydraulic limes, mixed with gravel alone. A proportion of sand must necessarily be added, and, contrary to the opinion which I have heard advanced by some practical men, it appeared, that coarse sand entirely unmixed with fine was not to be recommended, either as an ingredient for concrete, or for making mortar.

(141) Having tried a similar course of experiments with our three sorts of artificial hydraulic lime, made as before described (138), at the same time, and treated precisely in the same way, we could not decide which of them was the best, for they proved nearly alike in quality, notwithstanding the different proportions of chalk in their composition, and they all seemed fully equal if not superior to the Halling lime, for the purpose of making concrete or artificial stone.

(142) On afterwards comparing together the concretes made with boiling water, and those made with cold water, we could not discover that the former were in any respect better than the latter, although they had always begun to set sooner, so that, as our number of moulds was limited, we had been able to work more quickly with boiling water than with cold.*

(143) At the same time we had attempted to form similar concretes, both with our artificial cement and with Sheppy cement of good quality, mixing one measure of each in the state of calcined powder, with the same various proportions of gravel or of coarse or fine sand, which we had before used. Some of these in which the gravel and sand were in excess, would not adhere together at all, but crumbled into rubbish, as soon as the mould in which they had been made was taken to pieces. Others did not absolutely fail in this manner, but none of them were good for any thing, and all fell to pieces, when put under water, in fifteen hours after they were made. In fact, the proportion of gravel and sand used, not being less than 6 to 1 of cement powder in any of these mixtures, was enough in all of them to kill the cement, which circumstance, together with other observations and experiments, led me to the conclusion before stated, that cement is always weakened by sand (42). The goodness of the artificial and natural cements, used in these fruitless attempts to make concrete with gravel and sand, in the proportions stated, could not be doubted, since both of them, when made up into moist balls of net cement in the usual manner, set under water in ten minutes after they had been mixed, and on being taken

---

* I cannot discover any other advantage than this in the use of boiling water, and I doubt still more the benefit supposed to arise from heating the gravel and sand for artificial stones, another expedient resorted to by Mr. Ranger.

out next day, we were obliged to use a hammer and chisel for the purpose of breaking them.

(144) We afterwards tried another course of experiments on concrete with the same small moulds, in which, instead of varying the proportions of gravel and of the two sorts of sand used, we only employed one kind of sandy gravel, namely, Thames ballast, of the same description actually used by Mr. Ranger in making his artificial stones for the new works in Chatham Dockyard, excepting that, considering the smallness of our own moulds, we excluded all the pebbles that would have been disproportionately large, by screening the ballast through clear openings of half an inch in width, and using only the sand and finer parts of the gravel which had passed through the screen. Thus the sandy gravel in this second course of experiments was all exactly alike, which we considered necessary, in order to ascertain what proportions of the same sort of silicious matter were most suitable to the various kinds of cement or lime experimented upon; for in consequence of former experiments, in which we found that cement and the more powerful hydraulic limes would not bear so much of the same kind of sand, in making them into mortar, as the less powerful hydraulic limes, and still less than pure lime, it seemed reasonable to suppose that the same property would hold good in concrete.*

To ascertain this point, in the second course of experiments with our little moulds now alluded to, we mixed 1 measure of Sheppy cement with from 2 to 9 measures of the screened ballast, and 1 measure of each of the various sorts of lime with from 3 to 10 measures of ballast; and on examining all the concretes thus formed at the end of about six weeks, without putting them into water at all, we found that 2 measures of ballast to 1 measure of Sheppy cement, 5 or 6 measures of ballast to 1 of blue lias lime, 6 or 7 measures of ballast to 1 of Halling lime, and 7 or 8 measures of ballast to 1 of chalk lime, appeared to be the best proportions for making concrete with these several sorts of cement or of lime; and we were of opinion, that they would all be nearly equally efficient in those several proportions, if used in dry soil, but not in damp or wet soil, where the chalk lime concrete would be sure to fail. The very small quantity of gravel or sand which the cement in those experiments proved capable of bearing, when compared with the limes, confirms the opinion before advanced and supported by other observations and experiments, that cement should not generally be used for concrete (61), but if so used, that no fine sand should be allowed to form a part of the mixture; for as I have repeatedly mentioned, as an important distinction, the water cements are weakened, whilst all limes are strengthened by fine sand (42).

---

* That is, provided that the gravel and sand should not vary in their quality or proportions, as was the case in the first course of experiments just recorded, for this variation in the silicious matter used in concrete, renders the true proportion of lime brought into efficient action as a cementing substance very uncertain, from the circumstances before taken into consideration, in Articles 34 and 36.

(145) I shall here take the opportunity of introducing a remark on stucco, which perhaps may apply also to the external surface of Ranger's artificial stones. It appears to me, that good water cement mixed with very coarse sand is far more suitable for stucco, even than the best and strongest limes, and that to make it perfect, nothing more is required than to improve upon the present careless mode of applying it, before commented upon in Articles 121 and 122, and to work it up into so smooth a surface as to render it water-tight, which would prevent vegetation or moss forming upon it. Next to cement, but as I repeat far inferior to it, in their power of forming a good stucco, are those limes which approach the nearest to cement in their properties, such as the blue lias lime, which sets into a much harder substance, and resists the vicissitudes of air, rain, and frost, better than the weaker hydraulic limes, such as the Dorking and Halling limes. In fact, the weak hydraulic limes, though good for concrete in the dampest situations, and also good for the mortar of walls and foundations, are comparatively unfit for stucco, since they approach too nearly in their quality to the pure carbonates of lime, such as chalk, &c., which are altogether inapplicable to that purpose. I think it probable, that there are many excellent hydraulic limes in various parts of England, which from the expense of carriage cannot be brought into the London market; but the only lime of this kind that I am personally acquainted with, and of which I sent for some, after hearing it praised by an experienced builder, of London, was from Rosehill, in Sussex. I never saw this lime in its natural state, as the only specimen I could obtain, which was forwarded to me in a bag, had been previously burned, and probably ground, for it was in fine powder, and so very stale that it threw out scarcely any heat, on being mixed with water.* I therefore made it up into balls with water, which

---

* From the description of it in Mantell's Geology of Sussex, I infer that it is a hard lime stone. The specimen of it sent to me was from the estate of the late well-known John Fuller, Esq., long one of the Members of Parliament for that county.

when dry I burned in crucibles, knowing that reburning restores stale or slaked lime to its original state of quick lime. On trying the Rosehill lime in this improved state, in the usual manner, by making it up into moist balls after pounding it when fresh from the fire, it appeared to approach very nearly to a water cement; for on allowing these balls, which now threw out great heat, about a quarter of an hour to cool, and then immersing them in a basin of water, they did not go to pieces for several weeks, so that this lime seemed rather superior in its hydraulic powers, even to the blue lias of Lyme Regis, the best lime with which I had an opportunity of comparing it.

FURTHER EXPERIMENTS ON ARTIFICIAL CEMENT TRIED IN 1836.

(146) All our former experiments having been performed by manual labour, I resolved, before I published my observations, to ascertain practically the best mode of mixing artificial cement on a great scale, and it appeared to me, that the washmill, such as is used by whitening-makers, would be the best machine for grinding the chalk, and that the pugmill would be the best mode of mixing it with the blue clay; for I did not approve of the system that had been adopted by Mr. Frost, in his artificial cement works near Northfleet, of passing not only his chalk but his clay through the washmill, and afterwards drying the mixture by long exposure to air, both of which processes I believed to be injudicious; for to the former I ascribed the failure in 1829, and to the latter the failure in 1830, of my first attempts to make artificial cement on a great scale, before recorded. (See from Article 108 to 111 inclusive.)

(147) *Mode of grinding Chalk into Whitening.* The process of making whitening is this. After the chalk, previously broken into small pieces, has been ground with excess of water, in a washmill, where it is subjected to the action of iron rollers and harrows in an annular groove, the lighter parts of this fluid mixture are allowed to run off by a small channel into a *back* or reservoir, from which they are afterwards taken out, and made up into lumps or cakes of *whitening*, which, from the experiments of former years, I knew to be a good ingredient for artificial cement, but far too expensive. The heavier portion of the same fluid mixture of crushed chalk, which settles at the bottom of the groove, and which by a curious misnomer is called *sand*, is rejected by the whitening-makers, and considered of no value. Having examined some

of this substance which seemed fine enough for the purpose, I caused it to be dried and reduced to powder, in order to try whether it might not, as an ingredient for artificial cement, be made of some use, instead of being carted away for rubbish.

(148) Having made a little pugmill, and put into it alternately small portions of this whitening-makers' sand and of blue clay fresh from the river, until it was quite full, the aggregate of these ingredients having been previously measured in the proportion of 5 parts of the former to 2 of the latter, and having passed the whole through the pugmill two or three times, after which it seemed exceedingly well mixed, we burned it in the usual manner, expecting that this experiment would prove whether the proposed system of using the washmill for grinding chalk, and the pugmill for mixing it afterwards with clay, was likely to prove satisfactory, in making artificial cement on a great scale.

As the calcined cement obtained by this process would not set under water at all, it seemed probable that whitening-makers' sand might be an adulterated form of chalk, and therefore we next tried the whitening itself, and afterwards pure chalk from the quarry, reducing them both to fine dry powder, and mixing them with blue clay, in the same approved proportion of 5 parts of the former to 2 of the latter, by means of the pugmill; but as these also formed imperfect cements, that would not set under water, the fault seemed to rest with the pugmill, and therefore we tried the same ingredients mixed by hand with the greatest care, in the same proportion, and to our great surprise the cements formed with them, which had never failed in former years, now invariably went to pieces on immersion in a basin of water. These contradictory results at first appeared to me perfectly unaccountable, for I had no suspicion that the blue clay of the Medway could have changed its chemical character, and I could not doubt the accuracy of our former experiments of 1828 and the following years, in all of which the proportion of 5 measures of chalk to 2 measures of blue clay had yielded a cement, which appeared by the experiments on its strength before recorded in Articles 131, 133, and 134, to be fully equal if not superior in tenacity to the average of the natural cements of approved quality, as sold by the most respectable manufacturers; and which, as I never omitted to put every batch of it to that test, had always set under water, on being immersed, in about five minutes after it had been made up into moist balls. Finding therefore that this same mixture now invariably failed, I proceeded, but under these perplexing circumstances, almost in despair of arriving at a more satisfactory result, to try a number of other proportions of chalk and of blue clay, always retaining 5 measures of chalk powder, but using no less than six several proportions of blue clay, mixed with the above, and gradually increasing from 2¼ to 5 measures of this clay.

(149) The mixture of 5 to 5 in which the clay was in excess, would neither set in air nor in water. The other proportions, between 5 to 2¼, and 5 to 4½, inclusive, formed water cements; but both the former, which set quickly and with great heat, generally into a very light brown, but sometimes into a dirty white or light drab coloured cement, and the latter, which set very slowly and with scarcely any perceptible heat, into a very dark brown coloured cement outside, and sometimes of a dark bluish green colour inside, occasionally failed. All the intermediate proportions between these two extremes were better, but 5 to 3 appeared to be one of the best. The balls, of about 1 inch in diameter, made of this mixture, set into an excellent water cement, which when broken by a chisel in about 24 hours, proved equally hard inside and outside, and when allowed to remain two or three days before breaking them, were of a stony hardness throughout.

(150) In this new course of experiments for obtaining proportion, we observed that the best mixtures were those which when immersed were of a nut brown colour, and which in setting became rather warm than hot, attaining their highest temperature in from 7 to 10 or 12 minutes after being made up into balls with water. Those which set more quickly and heated violently from having an excess of chalk, as well as those which set much more slowly and without perceptible warmth, from having an excess of blue clay in their composition, and which were respectively of a much lighter and of a much darker colour than the above, were both of inferior quality.

(151) On now trying the whitening-makers' sand two or three times, mixed with a greater proportion of clay than before, we found that it made a tolerably good water cement, but apparently not equal to that formed with purer chalk. It is possible, however, that it might have succeeded better, if tried oftener, but on consideration I did not think it worth while to give it a further trial, as it appeared probable, that the manufacturers of artificial cement would prefer grinding their own chalk, instead of purchasing the refuse of the whitening-makers' washmills. Having compared the specific gravity of the whitening-makers' sand with that of pure

chalk, after reducing both to a fine dry powder, we found that the former exceeded the latter in the proportion of 5 to 3. Hence this sand must contain a good deal of foreign matter, probably of ground flints mixed with the chalk, of which it is chiefly composed.

(152) It is to be remarked, that in the experiments now alluded to, all those mixtures which formed a good artificial water cement, succeeded equally well, whether the ingredients were mixed by hand or in our little pugmill, but of these two modes, the latter was decidedly the best.

(153) At this period I remained for some time of opinion, that I must have been too hasty in adopting the rule laid down by me in 1828, and followed in the succeeding years, as to the best proportion of pulverized chalk and of blue clay for an artificial water cement; for although I had always taken the greatest pains to be accurate, I thought it much more probable that my own first experiments in 1828, which, so far as regarded the determination of the said proportion, were very few indeed, compared with other objects of inquiry, should have been in error, than that the alluvial clay of the Medway should have changed its chemical character in six or seven years. I conceive, however, on further reflection, that a partial change in the nature of the blue clay must necessarily have taken place in that period, without which, the general success of our original mixture is perfectly incompatible with the constant failure of the same proportion of chalk and blue clay in 1836. The impression upon my mind until the failures alluded to, always was, that the blue alluvial clay of the Medway contained very little calcareous matter, if any: but on referring to my original analytical experiments of 1828 and 1829, I could not find any record of my ever having tested the blue clay at that time, in such a manner as to ascertain this point with proper precision. But after the subsequent course of experiments now alluded to, having subjected the blue clay of the Medway obtained from the usual spot, just below Chatham Dockyard, to the action of the diluted muriatic acid, a brisk effervescence took place, which continued so long as to prove that this clay had become impregnated with a considerable proportion of calcareous matter, which most probably has always been the case, in a river flowing through a considerable tract of country having a subsoil of chalk, and abounding in lime works, which in the mean time had been multiplied on both banks of the river from Rochester towards Aylesford. Hence the difference between the results of these and

of the first experiments tried by me may be accounted for, by supposing a moderate increase to have taken place, in the proportion of calcareous matter contained in the blue clay, within the period alluded to.* The blue clay of 1828-9 being rather purer alluvial clay, formed a good water cement when mixed with chalk in the proportion of 2 measures of the former to 5 of the latter, that is, as 1 of clay to 2½ of chalk; whilst the alluvial clay of 1836 having more calcareous matter mixed with it, required a smaller proportion of the latter substance to produce a like result, the new proportion, which produced a water cement nearly of the same quality as our original artificial cement, being nearly as 2¼ to 5, or as 1 of clay to $2\frac{2}{9}$ of pulverized chalk. Thus the blue clay of the Medway of 1828-9, formed a good water cement when mixed with about 11 per cent. more of pure carbonate of lime than was required to be mixed with an equal quantity of the more calcareous blue clay of the same part of the river in 1836, in order to produce a similar result.

(154) Hence, also, though the best proportion of pure chalk and of pure alluvial clay for making artificial cement, might be laid down with great accuracy; one cannot determine before-hand the proportion necessary, for the same purpose, in working with chalk mixed with silicious or argillaceous matter, such as whitening-makers' sand or marl, or in working with clay mixed with calcareous matter, either of which, although if fine enough, they may be excellent ingredients for an artificial water cement, will require very different proportions from those which are suitable for pure chalk mixed with pure clay.

During the period that I was doubtful of the accuracy of my first experiments with chalk and blue clay, tried in 1828 and the years immediately following, it appeared necessary not only to fix a new and more judicious proportion of those ingredients, which was accomplished as related in Article 140, but also to repeat other experiments of those years, in order to ascertain whether the failures of our first attempts to make artificial cement on a great scale, in 1829 and 1830, were really owing to the circumstances to which we then ascribed them, or whether they might not have arisen partly or chiefly from the then defective proportion of our ingredients, namely, 5 of chalk to 2 of clay, which was apparently proved to be erroneous by our subsequent experiments of 1836. With this view we proceeded as follows.

---

* If so, it appears to me most probable, that the additional proportion of calcareous matter had been chiefly obtained from the new works then in progress, and from the wharf walls in Chatham Dockyard, whilst being pulled down and rebuilt, the lime of both having been subject to the action of land springs in the foundations, and of the tide above that level. The great quantity of chalk rubbish collected near the mouth of the Gravesend Canal Tunnel, opposite to Rochester, and the lime works at Cuxton, Halling, and Burham, &c., on the banks of the river above that city, may also have had their effect.

(155) First, we mixed 5 measures of chalk powder with 3 measures of the brown alluvial clay or surface clay of the Medway, this being the new approved proportion for our cement mixtures of the year 1836, which on being burned and treated in the usual manner, promised remarkably well at first, but always failed in the course of a few days, in precisely the same manner as the mixture of the like ingredients, but somewhat differently proportioned, had always failed in our original experiments (84).

(156) Secondly, we mixed 5 measures of chalk powder with 3 measures of blue clay, which, when burned without loss of time, had always formed an excellent cement, and having put part of this mixture into a tub with about four times its bulk of water, we stirred up together two or three times a day for a fortnight, after which the raw cement was allowed to settle to the bottom of the tub, and the clear water from above was drawn off by a syphon. As this mixture, which had been protected from air by the water, had not lost its blue colour, except at the surface, I thought it probable that the fortnight's washing might not have injured it, but such was the case, for on burning the blue part of the mixture, the cement balls formed of it either fell to pieces under water, or held together in an unsatisfactory manner, without setting into a hard substance.

(157) Thirdly, the same cement mixture, when properly prepared for use, and allowed to dry in the sun, retained its blue colour under the surface with so much obstinacy, that we were obliged to bruise it in a mortar, and cut it into very small pieces, and spread it out in this state, to admit air freely, before an entire change of colour could be produced. We then mixed it with water into a stiff paste, and burned it in the usual manner, into an artificial cement, which was rather of inferior quality; for although it set well under water, and sounded well when taken up and thrown against the side of a basin, yet it remained soft at the surface, and stained the hand when rubbed against it, much longer, than any of our good artificial cements had done; and the experimental balls formed of it were two months in attaining a satisfactory state of hardness, such as the same mixture, if burned without loss of time, and consequently without allowing the clay to become

stale by exposure to air, would have exhibited in the course of a week.

(158) Fourthly, on taking part of the same mixture, which had been washed for a fortnight, as described in Article 156, and which by that process alone appeared to be very much injured, and afterwards spreading it out to dry, until it completely lost its blue colour, and burning it; the experimental balls formed of it, instead of being entirely ruined by the second process, which the experience of former years had taught us to reprobate, never failed in setting under water, although they indurated rather more slowly than cement balls made of the same mixture had done, when burned immediately without washing and drying. As the experiments described in this and the two preceding Articles appeared rather contradictory, we thought it desirable to repeat them afterwards with a different mixture, which we ascertained to be a still more powerful artificial cement than the former.

(159) This was composed of 5 measures of chalk powder, mixed with 2½ measures of blue clay only, being a little less than the proportion of clay last used. On subjecting this mixture successively to the processes, first, of drying until it lost its blue colour; secondly, of washing and stirring for a fortnight; and thirdly, of washing and stirring, and afterwards drying, to entire loss of colour; the experimental balls formed of it under all those circumstances invariably set well under water, without staining the hand for any considerable length of time. Those subjected to the first process only did not appear at all injured, and the others also attained by degrees a satisfactory state of induration, but rather more slowly, than balls of the same mixture burned immediately, and without washing or drying, had generally done.

(160) Thus of our two new mixtures of 1836, one was occasionally but not generally spoiled, and when not spoiled, it was only deteriorated by the three processes now under discussion; whilst the second was never spoiled, and apparently very little injured by any of those processes. It seems therefore reasonable, to ascribe the difference between the effects produced by washing, and by drying with change of colour, upon our cement mixture of 1829 and 1830, and our second mixture of 1836, to the circumstance that the former was calculated to produce a very quick setting cement, and the latter to produce a cement of medium quality, equally removed from the two extremes, of those that set too quickly with violent heat, and of those that set too slowly without heat; the former of which are liable to fail from having an

excess of calcareous, and the latter from having an excess of argillaceous matter, in their composition. Now as the cement mixture of 1829 and 1830 approached nearly to the former of these extremes, whilst the last described mixture of 1836 was equally removed from both, it may be allowed, that any circumstance having an injurious tendency might entirely ruin the former, whilst it might only slightly deteriorate the latter.

(161) Without having the means at this time of procuring any blue clay, in precisely the same state as that of the Medway from 1828 to 1830, I knew that the original approved proportion, then adopted by us, formed a very quick setting water cement, bordering upon one of the extremes, liable to failure; because we endeavoured to make it as similar as possible to the specimens of the natural Sheppy cement stone which we had procured from Sheerness, and which set so quickly, when burned by us and made into experimental balls, that they did not always allow us time for marking them with a few printers' types,* and with so much heat that they were sometimes painful to the hand. Having little or no experience at the former period, we naturally concluded, from the high reputation of the Sheppy cement, that these symptoms were a proof of excellence,† and that the inconvenience of setting too quickly was only to be surmounted by mixing the calcined cement with excess of water (47), or by allowing it to become rather stale by temporary exposure to air. I do not think now, that those specimens could have been in the best state in which that excellent cement may be found, for they must have had rather more of the carbonate of lime in their composition than was desirable. As a proof that they could not bear much more, I may observe, that in the course of the experiments previously tried by us, in order to ascertain by what additional substances of various kinds the natural cements might be spoiled, we found that the Sheppy cement stone then in our possession was so much deteriorated by being mixed with one-fourth of its own bulk of chalk, both being previously reduced to and measured in the state of dry powder, that after this addition it entirely lost the property of setting under water; which experiment ought to have been inserted

---

* As examples of the mode of marking our experimental balls, C 5 B 2, F 27, 29, denotes five parts of chalk mixed with two of blue clay on the 27th February, 1829, whilst S, N 7, 30, denotes Sheppy cement, November the 7th, 1830. These symbols were marked in three lines to avoid confusion.

† This opinion was distinctly stated in Article 69, for it is to be observed, that the first edition of this Treatise, from the commencement to Article 146, inclusive, was printed before the experiments of the year 1836, which proved the fallacy of that opinion as to the superiority of very quick setting water cements, had been tried.

together with the others mentioned in Article 101, but was unintentionally omitted.

(162) To return to the new experiments now under consideration, having reason to believe from these that our artificial cement of 1829 and 1830 was not the best that might have been made with the same ingredients, it appeared desirable to ascertain which was the strongest, of four different proportions of chalk and blue clay, all capable of forming a water setting cement, by attaching bricks to a wall with each of them, until they broke down, in the mode represented in the lower projecting brick pier of the figure at the end of Article 131, marked *Row of Bricks standing out on edge.* This mode of trying the comparative strength of these mixtures was adopted, not only because experiments on a smaller scale would have been unsatisfactory, but also with a view to obtain a direct comparison of the tenacity of our own artificial cement, with that of the best natural water cements of England, the former of which had never been tested in this manner, but the latter frequently (132).

(163) But as it appeared probable, that the measurement of chalk in the state of powder might not be convenient, in working on a great scale, and as it is well known that weight is generally a more accurate test of quantity than measure,* I determined to fix the most suitable proportions for forming the best artificial cement with chalk and blue clay by weight, on a sufficiently large scale, and with so much precision as to leave nothing doubtful for the future; and in adopting this system, it appeared best always to weigh the blue clay fresh from the river, where it was obtained at low water at the depth of a foot or 18 inches below the brown surface, but not to weigh the chalk until previously well dried and pounded; and as the smallness of our apparatus required the raw cement, necessary for each of the four experimental brick piers, to be burned in several batches, making more than 20 in all, I directed a small but correct cube measure of each successive portion of blue clay and of chalk powder, used in those batches of raw cement, to be carefully weighed in grains, before the whole quantities required were weighed in pounds, in order to ascertain the average specific gravity of these two ingredients, which now proved to be 90 ℔s. per cubic foot for the blue clay, being a little more than our estimate of former

---

* As has been proved in several parts of a Treatise published by me in 1834, entitled 'Observations on the expediency and practicability of simplifying and 'improving the Measures, Weights, and Money, used in this country, without 'materially altering the present standards.'

years before stated (85), and 40 ℔s. per cubic foot for the dry chalk powder, measured lightly, according to our invariable practice in determining proportions.

(164) The necessity of weighing the chalk in a perfectly dry state, arises from its extraordinary retentiveness of moisture, from which I doubt whether it is ever obtained entirely free, even in the driest weather, and which cannot well be expelled from it, without breaking it into very small pieces, and drying them in the sun or before a fire. For example, a lump of pure chalk from any quarry near Chatham seldom weighs less than 100 ℔s. per cubic foot at any time, and after immersion in water it will weigh 113 ℔s., of which 23 consist of moisture, for when perfectly dry its average weight is only 90 ℔s. Thus the block chalk of that neighbourhood is capable of absorbing rather more than one-fourth of its own weight of water. More compact chalk equally pure, for in this respect it varies, would weigh more when dry, and gain less after immersion, than the above proportion.

(165) We have found by repeated experiments, that 2½ cubic feet of pure chalk powder, perfectly dry and measured lightly, when afterwards made up with water into a stiffish paste, of the consistency of mortar, will compress into the space of 1 cubic foot only, so that a cubic foot measure of chalk paste, thoroughly moist, but not quite so wet as the alluvial clay of rivers and lakes, will contain, as nearly as possible, the same quantity of chalk which if dry would weigh 100 ℔s.; and this mode of ascertaining the quantity of chalk previously pulverized, by wet measure, was considered by us, after due trial, to be more accurate than dry measure.

(166) Having thus explained, how far these three modes of ascertaining the true quantity of pulverized chalk by weight and measure agree, I shall describe the four new mixtures, all determined by weight, which we next proceeded to try, the first denoted by the emblem C B, in which the letter C denotes dry chalk powder, and B fresh blue clay, implying a mixture of equal weights of those two ingredients, whilst the next, C 4 B 5, implies a mixture of 4 parts of chalk with 5 of blue clay by weight, and so on, as stated in the following Table, in which the several symbols of each mixture are inserted and explained by weight; and their equivalents by measure, with the chalk both dry and wet, are also entered opposite, in reference to the data in the three preceding Articles.

TABLE OF CEMENT MIXTURES TRIED IN 1836.

PROPORTIONS BY WEIGHT.		EQUIVALENTS BY MEASURE.	
Mixture of C, chalk, and B, blue clay.	Or of dry chalk powder to fresh blue clay as	Dry chalk powder, measured lightly, to blue clay as	Stiff chalk paste to blue clay as
C B	1 to 1	5 to $2\frac{1}{4}$	1 to $1\frac{1}{8}$
C4 B5	1 to $1\frac{1}{4}$	5 to $2\frac{7}{9}$	1 to $1\frac{7}{18}$
C3 B4	1 to $1\frac{1}{3}$	5 to $2\frac{26}{27}$	1 to $1\frac{13}{27}$
C2 B3	1 to $1\frac{1}{2}$	5 to $3\frac{1}{3}$	1 to $1\frac{2}{3}$

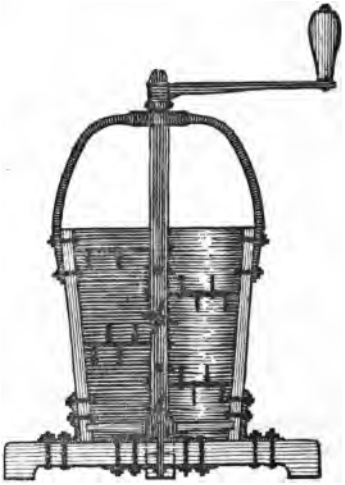
As the experiments, which I proposed to try with these mixtures, demanded too great a quantity of cement to admit of its being prepared in a common fire-place, but not enough to require the use of the small lime-kiln at Gillingham, before described (112), which was also at an inconvenient distance from the Barracks, I had a little iron furnace made as a substitute for a kiln, under the superintendence of Mr. Robert Howe,* whom I requested to keep the journal of the proposed experiments, as I expected to be absent part of the time that they were likely to occupy; he having also previously assisted me in the most interesting of the experiments tried some years before, for ascertaining the strength of our artificial cement (133 and 134), and in all the recent experiments on a small scale in respect to artificial stone or concrete (from 137 to 144 inclusive), in which he was himself the manipulator.

As the little furnace alluded to, and indeed the whole of the apparatus now employed by us, and also made under Mr. Howe's superintendence, might be very useful hereafter, not only to any gentleman who might be desirous of making similar experiments upon artificial cement, but also to the future manufacturers of that important article, who may prefer testing the quality of any new or doubtful mixture upon a small scale, instead of burning a large kilnful for this purpose, it may be proper to describe our apparatus.

(167) The pugmill in which our chalk powder and clay were mixed, which is represented in section in the following figure, was a correct model of the most approved form of that useful machine, excepting the little iron lever at top, which was cut short for a man to work it by hand, instead of representing the usual wooden lever, of much greater

---

* Who was Clerk of Works at the Royal Engineer Establishment, Chatham, from its first formation, and also subsequently Professor of Practical Architecture to the junior Officers, to which duty Mr. Howe was appointed, in consequence of his superior qualifications and merit. This year (1845) he has retired on a superannuation allowance, after long and most faithful services.



proportional length, worked by a horse. The essential parts of the pugmill are, first, a vessel for holding the ingredients to be mixed, which in our model was like a small bucket, 8 inches deep, and measuring 5 inches at bottom, and 6½ at top, in clear diameter; and secondly, a vertical iron spindle, with knives and teeth attached to it, which is secured to an iron bow at the top of the vessel, from which it can be disengaged by drawing out a forelock, and has a socket, working upon a pivot at the bottom of it. There were eight iron double-edged knives, each about an inch broad at the end, placed at equidistant heights, within the vessel, and radiating from the four sides of the iron spindle, to which they are fixed, towards the sides of the vessel, which they nearly meet. Four of these appear in full length in the figure, whilst the others are foreshortened, being seen in transverse section or in end elevation. The uppermost knife had two much smaller knives or teeth fixed nearly at right angles to it, and pointing downwards, as shown in the figure. All the other knives had four similar teeth, two pointing downwards and two upwards, excepting the undermost, which had only two pointing upwards. It will be observed, that the two edges of each knife are not on the same level, but have a moderate slope, though they are all placed horizontally in the general direction of their length. Hence as the axis revolves, the mixture that is to be incorporated, is cut through and through in a vertical direction by the teeth, and in a horizontal direction by the knives, the obliquity of which serves at the same time to force it lower and lower down the vessel by continual spirals, until it is squeezed out at a small hole on one side of the bottom.*

---

* From 3 to 3½ feet in clear diameter at top, and also in height, are the usual dimensions of pugmills. When filled from wheelbarrows, they are sometimes raised 9 inches or a foot higher than the above on one side. They seldom have a continued bottom, but merely a strong cross of woodwork resting on the ground, as a base for the vessel, in the centre of which cross the spindle moves. Recently iron pugmills have come into use.

(168) In preparing the ingredients for the pugmill, the dry chalk powder and the proper proportion of blue clay were weighed separately, after which the dry chalk was mixed with water until it became a stiff paste,* and the whole quantity of chalk paste and of blue clay were then each divided into 16 equal portions or lumps, with as much accuracy as this could be done by the eye. These small lumps of chalk paste and of blue clay were then put into the pugmill, alternately and in regular succession, until the whole space was filled with these ingredients, which were mixed by working the lever; and as fast as the raw cement was forced out from the bottom of the mill, it was taken up by a spatula, and put in at the top again, until the whole of it had passed about four times through the mill, which was done in order to keep the vessel always full, without which the cutting apparatus does not act, it being understood, that in using the real pugmill, new materials are always added, instead of passing the same through it more than once.

The pugmill contained conveniently about one-twelfth part of a cubic foot of raw cement, which, after being properly mixed, was made up into nearly equal balls of about two inches and a half in diameter, after which they were burned in the small furnace, which shall next be described.

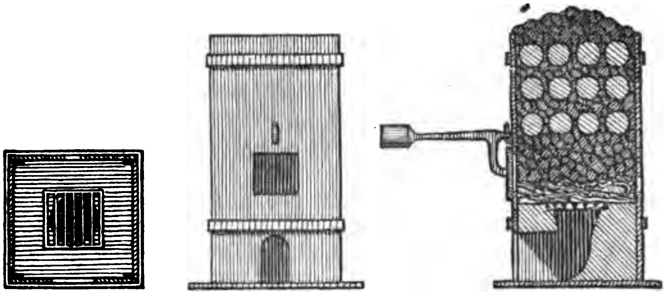
(169) This was 2 feet high and 11¾ inches square in the clear, being made of one entire plate of ⅜-inch boiler-plate-iron of the standard dimensions of 2 feet by 4, full measure, cut into four pieces for the sides, which were held together by two square iron hoops outside, and prevented from collapsing by iron studs inside. A small square grate, having half-inch bars and half-inch openings, was placed 8 inches from the bottom of this furnace, with an ash-hole below it, and a small moveable iron door above it, fixed upon a hook towards the top of the furnace, and kept close shut by the weight of a handle, long enough to allow a person to take it off when hot, without inconvenience. The space below the level of the grate was contracted by a mixture of silicious road scrapings, with a small proportion of clay, well rammed round an upright wooden cylinder or core, in the centre of the furnace, to which an opening was cut horizontally by a knife from the mouth of the ash-hole, and in the same form.

---

* The quantity of water was not usually weighed, but we have ascertained that our chalk powder perfectly dry required on an average about ¼th of its own weight, or about ⅛th of its own bulk, of water, to bring it into this state. This water was necessary, because the clay, though wet itself, had not spare water enough to bring the compound formed by adding the chalk to it, into a sufficiently moist state for use.

The wooden core was then taken out, and the grate placed and bedded upon the mass of rammed earth, the form of which was altered or improved a little, by paring away with the knife, or adding by the hand. A moderate fire was then lighted, and kept up for a few hours to dry and partially burn the mixture of road scrapings, &c., below the grate, after which the kiln was ready for use. The following figures will sufficiently explain these particulars.

SMALL IRON FURNACE USED AS A CEMENT-KILN.



1 *Plan.* 2 *Elevation.* 3 *Section.*

Fig. 1 is a plan, or horizontal section of the furnace, taken above the level of the grate. Fig. 2 is an elevation, showing the ash-hole and opening of the door, with the hook above it, but the door itself is supposed to be off. Fig. 3 is a vertical section of the kiln, having the door fixed, and supposed to be filled with fewel and raw cement in alternate layers, ready for burning, which were arranged as follows.

(170) Shavings and wood were laid first upon the grate, with coals or coke over them, to the height of 5 or 6 inches, which being lighted, the fire was blown by a pair of bellows through a hole left in one side of the furnace, a little above the level of the grate, until it burned well. Then a layer of cement balls was laid over the whole area, upon which a second layer of fewel was thrown, and then a second layer of cement balls laid, and so on; it being understood that the uppermost as well as the undermost of these alternate layers or courses always consisted of fewel. The little furnace could just hold 3 courses of cement balls, thus alternating with 4 courses of fewel, each course of those balls being nearly equivalent to the twelfth part of a cubic foot, or to one pugmillful of raw cement, whilst each course of fewel measured only about 2 inches in depth, except the undermost and uppermost, the latter of which was heaped.

(171) After trying both, we abandoned the use of coals altogether, because as our little furnace, though placed on the hearth of a smith's forge,* could not conveniently be brought under the chimney, the coals caused an intolerable smoke, and required the bellows to be kept blowing almost incessantly, and as they generally burned unequally, they either did not calcine the whole of the cement sufficiently, or spoiled a part of it by overburning. Moreover the coals were liable to cake, and required poking, which could not be done without breaking the cement balls. By burning coke, on the contrary, the nuisance of smoke was avoided, and after a clear fire with a strong red heat had been obtained, by using the bellows for about a quarter of an hour, it continued in the same satisfactory state, without any necessity either for blowing or poking it, until the cement was properly burned, which was usually accomplished in about three hours; and as part of the calcined cement could be drawn or taken out from the bottom, whilst more raw cement and fewel were added at top, without disturbing the fire, in the same manner as is done in a common lime-kiln, this little furnace might have been kept constantly burning night and day; but we seldom found it necessary to renew its contents, or to fill it more than once in the same day, although it might have been conveniently filled three times during the usual working hours. In *drawing* this little kiln, that is, in raking out the undermost of the calcined cement balls through the door, a small fragment of each was always tested by the diluted muriatic acid, and if effervescence took place, the balls were put in again at the top, along with more fewel, to be reburned (45). But if non-effervescence in the acid showed that they were burned enough, any clinkered or overburned portions, which occasionally occurred, were broken off and thrown away; and the remainder of the calcined cement was then ground and carefully bottled up for use, and every bottle labelled.

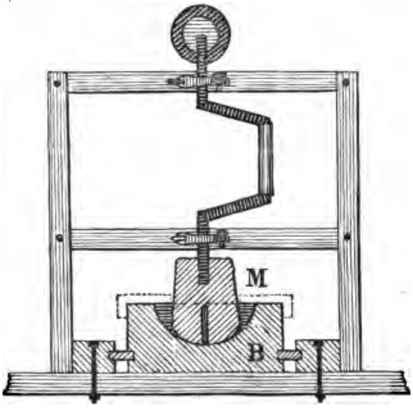
(172) The raw cement from the pugmill ought to yield an equal quantity or even a little more of calcined cement powder measured lightly; but owing to waste from overburning, &c., the average produce of 10 measures of our raw mixture was only 9½ measures of the cement powder.

(173) To grind our calcined cement we used a very simple and ingenious little mill, represented in the following figure,

---

* For this reason we made our bellows-hole on the far side of the furnace, opposite to the door, which would not have been convenient any where except in a smithy.

which did the same work in much less time and more effectually, than the common pestle and mortar.



Part of the Top *of the Tressel.*

The essential parts of this little machine, said to have been invented for grinding indigo dry, by Mr. Rawlinson of Derby,* are first the stone bed B, having a cavity cut in the upper part of it, in the form of a portion of a hollow sphere, serving as the mortar, and secondly, the upright stone or muller M, nearly of a cylindrical form, but having its bottom convex to suit the former, and acting as the pestle, in grinding the calcined cement, which it does by being made to revolve by turning a crank on its own vertical axis or spindle, which is loaded with a weight at top to give it greater power, for which purpose we used a 5½-inch shell filled with melted lead.

The Muller, which was 10 inches high and about 6 inches in diameter at bottom, had a rectangular hole cut entirely through the lower part of it, which was essential for the proper action of the machine; and to prevent the fragments and dust, which were whirled violently round, from flying out, the lower stone B, which was square in plan, was covered with a moveable wooden lid in two pieces, shown by the dotted lines, and embracing the muller.

The moving spindle was fixed to a wooden frame, and in order to prevent shaking, the whole apparatus shown in the figure was firmly bolted down to the top of a strong well framed wooden tressel, the other parts of which have been omitted for the sake of clearness.

---

* See the Article Drugmills, in Sir David Brewster's Edinburgh Encyclopædia. The inventor of this little machine is said to have been honoured by a medal of the Society for encouraging Arts, Commerce, and Manufactures.

(174) We tried the same little machine for grinding our chalk, but its performance was not satisfactory. In working dry, the chalk became caked between the two stones, and on trying to grind it wet, as in the washmill, we found that solid particles remained unbroken, corresponding with the whitening-makers' sand (147), which the form of the machine did not afford us the means of separating. We therefore, after having previously broken our chalk into small pieces, which we dried by a fire, or by placing them round our small furnace when in use, pounded it with an iron pestle, in a broken 10-inch shell, which we used in preference to a common mortar, sifting the chalk powder thus produced through the very fine sieve before described (108); for except in working on a very small scale, the use of a sieve cannot be dispensed with.

(175) It was before stated, that our object now was to compare the strength of four different mixtures, by setting out piers or rows of bricks on edge from a wall, with each sort of them; and as our recent experiments had made us of opinion that very quick setting was not desirable in a water cement, we resolved that we would only add one brick every day, Sundays excepted, in the following manner, to each of our four experimental piers, which were attached to one of the interior walls of what was originally the farriers' shoeing shop in the north stable-yard, Brompton Barracks.

In commencing each of our piers, a small rectangular portion of the wall sufficient for receiving the first brick had the whitewash scraped off, and the original joints of the brickwork raked out about half an inch in depth, which were filled with net cement, and then the first brick was attached to the face of the wall by more cement, applied before that in the joints had begun to set. Whenever a new brick was about to be added, it was immersed for half a minute in a bucket of water, and the face of the wall or brick already placed, to which it was to be attached, was wetted at the same time by the brush, after which cement was applied to both surfaces by a bricklayer, first in a thin coat to the wall or fixed brick, and then in a thicker coat to the new brick, pressing it down at first into the hollow in the centre of this second brick, in order to prevent the formation of those cavities or air cells, which sometimes occur in the joints of bricks, when put together with cement in a hasty manner, as we had observed in former experiments of the same nature (133). The new brick was then applied to the former, with cement against cement, by another man, who adjusted and pressed them together, first with his hands, and then by leaning forward and holding the point of a trowel against the centre of the back of the new brick, and as this pressure squeezed out a part of the cement on all sides, the bricklayer finished the joint by working up these projecting edges of moist cement all round with his trowel, pressing them in, and at the same time removing superfluous parts, so as to produce a smooth surface; during which process, and for some time afterwards, the other man still remained steadying the new brick, which he did not quit, until from 5 to 10 minutes after the cement for the joint had been mixed, allowing the longest time to those mixtures which had the largest proportion of clay. The average thickness of the cement joints thus formed was only a quarter of an inch, but owing to the hollow on one side, with which English bricks are purposely moulded, they were about half an inch thick in the centre. The bricks used in all our piers were handsome *Malms* or *Marl bricks*, selected from a brickfield near Chatham, and were previously rubbed together to take off the glaze from the surface, which was done without any perceptible diminution of their thickness. Each cement joint required about 18 cubic inches of cement powder, excepting the first joint connected with the face of the wall, which took double that quantity, in consequence of the original joints of chalk lime mortar, which would have been too weak, having been raked out and made good, as before stated.

(176) In this manner four brick piers were built simultaneously, adding one brick to each daily, by the same men, who commenced at four o'clock every afternoon, Sundays excepted as before said, with mixture C B, being the quickest setting mixture, and finishing with C 2 B 3, the slowest of the four, and continued this operation until the whole of the piers fell down, which occupied not less than 35 days, from the placing of the first brick on the 28th of September to the downfal of the last. During the whole of this period the little kiln was burning every day, also with the exception of Sundays, sometimes containing only one pugmillful of raw cement, sometimes three, which was the utmost that it was capable of holding, and which was equivalent to the fourth part of a cubic foot, but more usually containing two, or the sixth part of a cubic foot. It required a good deal of care and arrangement to avoid error, in preparing and serving out at the same time so many different sorts of cement for our experiments, which was done quite to my satisfaction by an acting Corpo-

ral,* who took charge of every process necessary in our little temporary cement manufactory, from the procuring of the raw materials, to the mixing of the calcined cement powder for the use of the bricklayer, whom he also assisted in pointing the joints. It rained almost incessantly during this period, which included three days of frost and snow, but very few of clear dry weather.†

(177) At the time that every new brick was added, we made one or two experimental balls of each mixture, and put them under water, which we changed daily, in order to judge also of their hydraulic properties; and with the exception of C B, in which chalk predominated, and which occasionally fell to pieces in the course of five or six days after immersion, all the others set remarkably well, and so did this mixture itself generally, for those balls which did not fail became very hard. Hence if we had only tried these mixtures on a small scale, we would have considered C B rather inferior from this circumstance, but we might have thought all the others excellent, and supposed them all to be equally good. This however was far from being the case, as we discovered from the results of our four experimental piers, which proved that there was a considerable difference in the strength of all these mixtures, and consequently convinced us of the great utility of this mode of comparison. The figures on the opposite page show the state of each pier before it fell, with its length at the average rate of only 2⅔ inches per brick, which is much less than the average thickness of the courses of common brickwork, and its weight at the average of about 6 lbs. per brick.‡

---

* Lance-Corporal John Down, who executed most of the other experiments of this year also, assisted by three military boys, of whom he had charge, he being the acting Bugle-Major. Private John Carter was the bricklayer employed. Private Edward Lowe, a mason, held every new brick whilst being placed.

† This damp state of the weather must have been unfavourable to our experiments, because in reference to the circumstance of Messrs. Francis, White, and Co. having set out 29 bricks from a wall by their best natural cement, as stated in Article 132, one of the partners informed me, that this could be done in one month in summer, but that it required two months to accomplish it in winter.

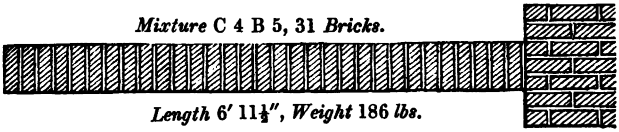
‡ The average weight of each of these bricks when quite dry was 5 lbs. 5 oz. The surplus weight was caused chiefly by the cement joint, but partly also by their being each saturated with water when placed, so that the last built portion of the pier was always in a damp state.

We also tried to set out a line of bricks from a wall, placing them with their greatest width downwards but end to end, or with the whole length of every brick at right angles to the wall. On allowing only a quarter of an hour for each, it was impossible for any of our cements to set out more than one brick, as the pier always broke down on the addition of a second. We therefore allowed one hour for each brick, and then mixture C B set out three bricks end to end, but on the addition of the fourth, when the pier measured 3 feet in length, it broke down. C 4 B 5 also set out four bricks, after which the pier broke down. Upon the whole we did not consider this sort of experimental pier to be at all satisfactory.

Mixture C B, which was generally of a light brown but sometimes of a dirty white colour, which last we had before ascertained to be an unfavourable symptom of a water cement (149), supported only 21 bricks, and in about half an hour after the last was placed, the pier gave way at the second joint from the wall, leaving two bricks standing.

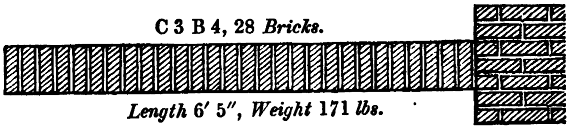
SECTIONS OF THE EXPERIMENTAL PIERS BEFORE THEY FELL.

Mixture C 4 B 5, 31 *Bricks.*



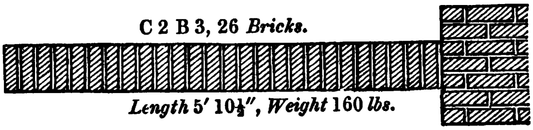
Length 6′ 11½″, *Weight* 186 *lbs.*

C 3 B 4, 28 *Bricks.*



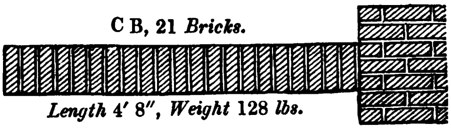
Length 6′ 5″, *Weight* 171 *lbs.*

C 2 B 3, 26 *Bricks.*



Length 5′ 10½″, *Weight* 160 *lbs.*

C B, 21 *Bricks.*



Length 4′ 8″, *Weight* 128 *lbs.*

Mixture C 2 B 3 supported 26 bricks, and mixture C 3 B 4 supported 28 bricks, after which each of their respective piers fell down some time in the night, separating at the wall joint, but tearing out small portions of the original red bricks belonging to the wall, which did not seem so good as those with which we operated. The above three piers, after detaching themselves from the wall by one joint only, were fractured in several other parts by falling, from the height of nearly 5 feet, down upon a floor paved with small hard stones; and in several of these last fractures, two adjacent bricks were broken obliquely, instead of the separation taking place uninterruptedly, in the continued direction of the cement joint, by which they had been connected.

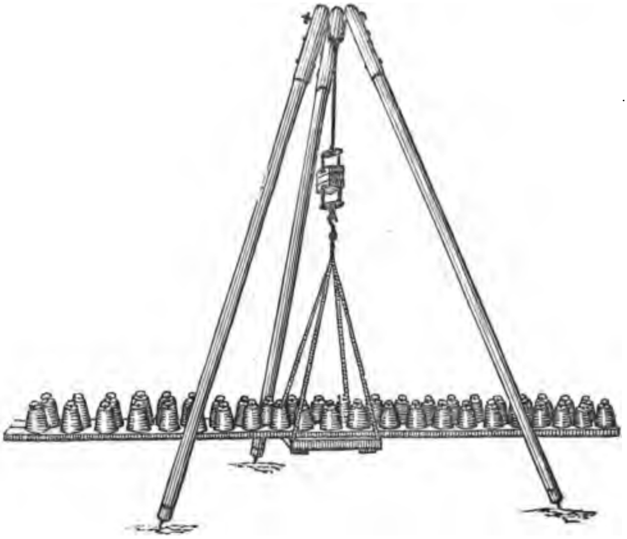
The smallness of the cement joints renders them much more liable to be deranged, during the placing of each new brick, than in the former method, and the leverage abruptly added, by one whole brick's length at once, is too great.

(178) Mixture C 4 B 5 supported 31 bricks, which projected 6 feet 11½ inches from the face of the wall, and weighed 189 lbs., and in 16 hours after the last brick had been placed, the pier gave way at the first joint from the wall, leaving one brick standing. The remainder of the pier, composed of a mass of 30 bricks cemented together, was prevented from breaking after detaching itself from the wall, by a plank covered with bags full of shavings, placed a little below it for this purpose.

Considering that this mode of setting out bricks from a wall, though an excellent test of the quality of different sorts of cement, if always done under the like circumstances, might be supposed doubtful, if executed by workmen of unequal skill, or not precisely in the same manner, and in different states of weather or of temperature; and considering also that a pier of this sort exhibited at the premises of any cement manufacturer might not be considered satisfactory, by persons who had not been actually present at the time the bricks were placed; since there can be no doubt, that by permanently supporting such piers for several months a much greater effect would be produced, than by the mode I have described of only holding each successive brick a few minutes by a trowel; it therefore appeared desirable, when we first prepared for commencing those experimental piers, to make arrangements also for trying the comparative strength of the same four artificial mixtures, by tearing them gradually to pieces by dead weight, in the manner before described in Article 133.

(179) For this purpose we cemented together little masses of three bricks each, having mortises cut in the upper and lower bricks for receiving the iron nippers before described, exactly similar to the mortises represented in the upper and lower bricks of the little mass of five bricks represented in the figure annexed to the same Article (133), which has just been quoted. With each of our four experimental mixtures, we cemented together two such masses, making eight in all, which afterwards we proceeded to tear asunder by weights in from 36 to 43 days after they were made; but instead of suspending our masses by a rope as before, we deemed it more convenient to use iron connecting rods, and as the scale board was too small to hold the necessary weights, instead of a cask to hold 24-pound shot, which we had used before, we now laid a couple of strong 12 feet 3 inch deals upon the scale board, and loaded them from the centre outwards by two or sometimes three parallel rows of iron half-

hundred weights, laid on one at a time, until fracture took place; taking great care that the men who applied them should always stand sideways, with their feet clear of the scale board and planks, which, together with the lower nippers, weighed 205 lbs., and in the records of our experiments, this was of course included as a part of the breaking weight.



Of mixture C B, the first sample broke down under 989 lbs., and the second under 1549 lbs.

Of mixture C 2 B 3, the first sample broke down under 1437, and the second under 1325 lbs.

Of mixture C 3 B 4, the first sample broke down under 1661, and the second under 1717 lbs.

Of mixture C 4 B 5, on trying the first sample in this manner, the apparatus broke down four times, twice under a weight of 2109 lbs,, and afterwards under weights of 2389 and of 2333 lbs., but on examination we found in all those cases that the iron work only had given way, whilst the bricks and cement remained perfect. On trying this same sample two days afterwards with stronger iron work, it gave way soon after 44 iron half-hundred weights were placed upon the planks over the scale board, as represented in the preceding figure, the total weight at this period being 2669 lbs.; but, on examination, the upper brick was found to have been torn entirely across from one mortise to the other, whilst the two cement joints were both perfect. The second sample of the same mixture gave way under 2109 lbs., but in this case also the uppermost brick only was torn to pieces.

(180) Thus the experiments for tearing asunder the cement joints of these little masses appeared to confirm the general results of the former, inasmuch as the average weights for rupturing them were smaller or greater, in proportion as each mixture had previously stuck out a smaller or greater number of bricks from the wall. These last experiments also seemed to prove that C 4 B 5, the best of our four experimental mixtures, was much stronger at the age of 38 or 40 days, but that the three others were weaker, than the select bricks used by us. In order to fracture the joints of this superior mixture, it therefore appeared necessary to adopt a different arrangement, by forming masses of four bricks, and making the mortises for the nippers in the middle of the second and third bricks of these masses, as represented in the annexed figure, by which means the solid part above and below the mortises is strengthened by the thickness of one entire brick and a cement joint, leaving the centre joint of cement only exposed to the full action of the breaking apparatus; and we therefore thought that this joint could not fail to be torn asunder before the bricks gave way. As the two samples of C B had broken under very unequal weights, it seemed desirable to expose more samples of all the four mixtures to the same action, in order to obtain an average for each mixture founded upon more experiments than two, and for this purpose we used portions of the brick piers previously broken down, as well as new cement. The results of the former and of these new experiments are contained in the following Table.

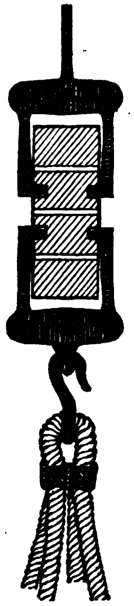


TABLE I. COMPARATIVE ADHESIVENESS OF VARIOUS ARTIFICIAL CEMENT MIXTURES TO BRICKS.

No. of the Experiment with each Mixture.	Proportions by weight of the Artificial Cement Mixture, of C, Chalk, and B, Blue Clay, and whether the Brickwork was an original Mass, or part of a Mass, or of a Pier, previously experimented upon.	Age of the Cement, in days.	Weight that tore asunder the Mass, in lbs.	The fracture took place in the
1	C B. No. 1, Mass	35	989	*Joint.*
2	C B. No. 2, Mass	35	1549	*Joint.*
3	C B. Part of Pier	58	2105	*Joint.*
4	C B. Remainder of No. 1	68	1549	BRICK.
5	C B. Remainder of No. 2	68	1885	*Joint.*

TABLE I. CONTINUED.

No. of the Experiment with each Mixture.	Proportions by weight of the Artificial Cement Mixture of C, Chalk, and B, Blue Clay, and whether the Brickwork was an original Mass, or part of a Mass, or of a Pier, previously experimented upon.	Age of the Cement, in days.	Weight that tore asunder the Mass, in ℔s.	The fracture took place in the
1	C 4 B 5. No. 1, Mass	38	2109	APPARATUS.
2	C 4 B 5. The same	38	2109	APPARATUS.
3	C 4 B 5. The same	38	2389	APPARATUS.
4	C 4 B 5. The same	38	2333	APPARATUS.
5	C 4 B 5. The same	40	2669	BRICK.
6	C 4 B 5. No. 2, Mass	40	2109	BRICK.
7	C 4 B 5. Part of a Pier	65	3257	BRICK.
8	C 4 B 5. Remainder of No. 1	74	2725	BRICK.
9	C 4 B 5. Remainder of No. 2	74	3117	BRICK.
1	C 3 B 4. No. 1, Mass	39	1661	*Joint.*
2	C 3 B 4. Remainder of No. 1.	39	1101	BRICK.
3	C 3 B 4. No. 2, Mass	39	1717	*Joint.*
4	C 3 B 4. Remainder of No. 2.	39	1325	*Joint.*
5	C 3 B 4. Part of a Pier	69	2525	BRICK.
6	C 3 B 4. Part of a Pier	74	4455	BRICK.
1	C 2 B 3. No. 1, Mass	39	1437	*Joint.*
2	C 2 B 3. No. 2, Mass	42	1325	*Joint.*
3	C 2 B 3. Part of a Pier	65	1965	*Joint.*
4	C 2 B 3. Part of a Pier	74	4009	BRICK.
5	C 2 B 3. Remainder of No. 1	75	2277	*Joint.*
6	C 2 B 3. Remainder of No. 2	75	1605	*Joint.*
7	C 2 B 3. Part of a Pier	91	3981	*Joint.*

(181) On examining the contents of the Table with attention, it will be evident that the induration of cement is more gradual than is generally supposed, since all those mixtures increased greatly in adhesive strength, by allowing some weeks longer for the cement to set, before the joints were subjected to the breaking apparatus. Thus, for example, whilst all were improved by age, mixture C 2 B 3, which had not borne more than 1437 ℔s. when 39 days old, bore 4009 ℔s. when 74 days old, in one experiment, in which the bricks gave way and not the joint. Also mixture C 3 B 4, which had only borne 1717 ℔s. when 39 days old, bore 4455 ℔s. when 74 days old, in one experiment, in which also the bricks broke down, for the new arrangement of the brick masses did not render them stronger than the cement, as we had expected; and unfortunately C 4 B 5, which proved to be the strongest of all our mixtures at 38 or 40 days old, was associated, after having attained the age of 65 and 74 days, with much weaker bricks than either of the two other mixtures that have been mentioned. But supposing this cement still to have retained its superiority over those two at the

above increased age, which at this period was probable, though not absolutely proved, it appeared to me that the average weight for tearing a joint of this mixture to pieces at 70 days old could not reasonably be estimated at less than 5000 lbs.

It may be observed, in respect to the general increase of average adhesive strength by age, that the quickest setting cements appear soonest to come to a stand; for C B increased by far the least of all, in proportion to its age. We did not know what the increase of C 4 B 5, the next in order in this quality, might have been; but the increase of C 3 B 4, and that of C 2 B 3, the two next in order, and the slowest setting cements of the whole, were very remarkable. And unless experiments of the same kind were tried with hard stone instead of bricks, it is impossible to say, whether these three last mixtures may not, by trying them at still greater ages than 70 days, require much greater weights than 4000 or 5000 lbs. to break them down. It is also doubtful, whether as they all grow still older, the slowest setting cement, C 2 B 3, may not gain upon C 3 B 4, and both upon C 4 B 5. In the mean time, it may be observed, that this last cement acquired in the space of 40 days much greater strength than the best bricks that we were able to procure in the neighbourhood of Chatham, which I believe to be as good as any made in England.

ADDITIONAL EXPERIMENTS ON THE COMPARATIVE ADHESIVE STRENGTH OF QUICK SETTING AND SLOWER SETTING CEMENTS, BY STICKING OUT BRICKS FROM A WALL.

(182) Having some doubts, whether the common mode of setting out bricks from a wall in shorter periods than one day, was a fair trial of the comparative cohesive strength of cements, I tried C B, the quickest setting, against C 4 B 5, then considered the strongest of our cement mixtures, by sticking out bricks from a wall with each, in the same manner that was before described in Article 178, but in a much shorter time, allowing only a quarter of an hour, instead of one whole day, for the setting of each brick.

Adopting this arrangement, C B supported 12 bricks, after which the pier fell down, but on examining one of the joints, it had evidently been injured by moving the last brick, in placing it whilst the cement was setting; and therefore we gave this proportion a second trial, taking care to mix the cement very thin, and indeed almost in a fluid state, in order to prevent its setting before each new brick was definitely placed. Using this precaution, mixture C B set out 18 bricks from the wall.

C 4 B 5, the strongest of our mixtures, on the contrary, only supported 12 bricks when applied at intervals of a quarter of an hour. On trying the same mixture by setting out bricks at intervals of half an hour, it supported 18 bricks, after which it fell down. But on trying it a third time, with intervals of one hour per brick, it supported 24 bricks before the pier fell down, which was a greater number than C B had supported at intervals of one day per brick.

THAT THE MODE OF TRYING THE COMPARATIVE ADHESIVE STRENGTH OF TWO DIFFERENT SORTS OF CEMENT, BY STICKING OUT BRICK PIERS FROM A WALL WITH EACH, IS UNCERTAIN, UNLESS MORE PIERS BE MADE, AND MORE TIME AND TROUBLE GIVEN TO THIS SORT OF TRIAL, THAN WOULD GENERALLY BE CONVENIENT.

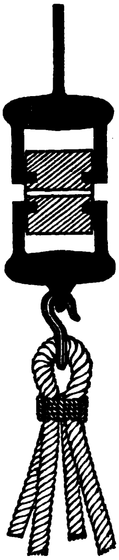
(183) From these last experiments, it may be inferred, that in trying the comparative adhesive strength of two sorts of cement by setting out brick piers from a wall, the intervals allowed for the placing of each brick should be in proportion to the time required by the slowest setting cement of the two; otherwise an erroneous result may be obtained; for at shorter intervals, the quickest setting cement, though from that very property less fit for the purposes of Practical Architecture, and in reality the weakest of the two, may stick out the greatest number of bricks.

But as two experimental piers only, one for each sort of cement, might be liable to error, from the great risk of the last cement joint of each being disturbed, whilst every new brick is being placed, which risk increases in proportion to the length of the pier; I consider that to insure any thing like certainty, six such piers, three for each sort of cement, would be necessary, in order to afford a just average of comparative strength; and as the intervals for placing successive bricks in both piers ought not to be less than one hour, or rather two hours for each brick, which would require the persons employed to work night and day, this arrangement would be attended with much trouble and inconvenience. If the workmen left off placing bricks during the night, which might be considered fair enough, as both cements would be treated alike, it would require two days to complete the trial at intervals of one hour, and three days to complete it at intervals of two hours, per brick: and in so doing, if the cements were both tolerably good, one cannot reckon upon using fewer than an average of 20 bricks for each pier, connected to the wall and to each other by the same number of cement joints, and amounting to 120 bricks and 120 joints in all. Besides which, no person who took a great interest in ascertaining the comparative goodness of the two cements accurately, would be satisfied with the result, unless he saw every brick placed himself. Hence this sort of trial, if executed fairly, would give more trouble and take up more time, than any man of business could conveniently devote to it.

(184) After the last experiments which have been recorded, though there seemed good reason for believing, that C 4 B 5 was the strongest of all the cement mixtures that we had yet tried; yet as it was not impossible but that some intermediate mixture, between this and C B, which differed from it in containing less, or between this and C 3 B 4, which differed from it in containing more blue clay, might be still stronger, it seemed desirable to ascertain this point by further experiments, by trying the same mixture in competition with some others, containing rather smaller or rather larger proportions of clay. But, for the reasons stated in the preceding Article, we determined to relinquish the embarrassing process of setting out bricks from a wall, and adopted a much simpler, less troublesome, and altogether more satisfactory method, in the new series of experiments, which shall next be described.

FINAL EXPERIMENTS TRIED IN 1837, FOR ASCERTAINING THE STRONGEST ARTIFICIAL CEMENT, THAT CAN BE MADE OF CHALK AND BLUE ALLUVIAL CLAY.

(185) The new mixtures were formed by combining the same invariable quantity of dry chalk powder, namely, 4 ℔s., with nine different proportions of fresh blue clay, differing from each other by 1-10th of a pound, and varying from 4 ℔s. 8-10ths, to 5 ℔s. 6-10ths, inclusive. It was not my intention to have gone farther than 5 ℔s. 3-10ths, but the results of the three higher proportions, though prepared by mistake, shall not be omitted; especially as they tended to set one of our former conclusions aside, thus proving the great advantage of multiplied experiments, in trials of this kind. By each of these mixtures, four or six small masses of bricks, or sometimes more, were cemented together in pairs, thus having only one joint in each mass, which we considered the safest mode of proceeding, because there is no risk of its being disturbed, which might be the case,



if a third brick requiring a second joint were added. Mortises for the nippers were cut in each pair of bricks in the usual manner, which, in order to give more strength to the bricks, were cut nearer to the common joint than to the top or bottom of the little mass, as shown in the annexed figure.* We fixed upon 10 days as the proper period for experimenting upon these little masses, by the breaking-down apparatus before described, which time we considered more than enough to afford a just estimate of the comparative strength, even of the slowest setting cements, being in fact five times longer than I had ever known to be allowed for any one joint, in the common mode of trying the strength of cements.† At the same time, from our former experiments, we concluded that the strongest cement, when only from 10 to 12 days old, would be so much weaker than well burned bricks, that we anticipated no trouble from any of the bricks giving way. The process now adopted was also very convenient, because after the mortises in the sides of the bricks are cut, it only requires one bricklayer and his assistant to be employed for a couple of hours in putting 10 masses together, consisting of 5 pairs of bricks each, which are quite sufficient for trying any two cements properly; and at the end of the ten days after the apparatus is prepared, the whole of them may be broken down also in a couple of hours, by the assistance of three or four labourers; both of which operations any man may attend personally without inconvenience.

In preparing for this experiment, we had selected the very best bricks that could be procured, partly clamp and partly kiln-burned, not only from the former brick works, but from two other brick-fields, all of which were well burned, ringing well when struck together, and most of them being paving bricks, weighing no less than 6½ lbs., on an average, when perfectly dry. We were therefore disappointed to find that an unusual number of these bricks gave way, instead of the cement, under weights much less than what bricks, apparently not superior to these in outward appearance, had borne without injury, in our former experiments. In fact, a sufficient number of cement joints did not break down to render this new set of experiments conclusive, the results of which, such as they are, have been entered in the following Table.

---

* A piece of cord, not shown in the figure, was always used to connect the lower nippers with the gyn, and prevent them from falling to the ground also, after the scale board and weights fell down.

† I allude to the usual mode of setting out bricks from a wall, for which purpose I have never known more than two days per joint to be allowed, which was only done in winter, when cement sets most slowly. See the second note to Article 176. It was not my intention to have allowed a longer period than 10 days for trying any of these mixtures, but the men employed understood that I meant what they termed 10 clear days for the cement to set, and therefore did not prepare the breaking-down apparatus, &c., for my inspection until the 11th day. Thirty days make a great difference in the adhesive strength of cement; but 2 or 3 additional days, or even 4 or 5, appear to make very little difference after the 10th day.

TABLE II. COMPARATIVE ADHESIVENESS OF VARIOUS ARTIFICIAL CEMENT MIXTURES TO BRICKS.

No. of Experiment.	Proportions of the Mixture by weight of C, Chalk, and B, Blue Clay.	Age of the Cement, in days.	Weight that tore asunder the Mass, in lbs.	The fracture took place in the	Average Adhesiveness, in lbs.
1	C 4 B 4·8	11	936	*Joint.*	997
2	C 4 B 4·8	11	1304	*Joint.*	
3	C 4 B 4·8	13	926	*Joint.*	
4	C 4 B 4·8	13	821	*Joint.*	
1	C 4 B 4·9	11	1409	BRICK.	1220
2	C 4 B 4·9	11	1374	*Joint.*	
3	C 4 B 4·9	13	1108	BRICK.	
4	C 4 B 4·9	13	989	BRICK.	
1	C 4 B 5	11	1227	*Joint.*	1359
2	C 4 B 5	11	1101	*Joint.*	
3	C 4 B 5	11	1493	*Joint.*	
4	C 4 B 5	11	1073	*Joint.*	
5	C 4 B 5	11	1409	*Joint.*	
6	C 4 B 5	11	1437	BRICK.	
7	C 4 B 5	11	1577	BRICK.	
8	C 4 B 5	11	1416	BRICK.	
9	C 4 B 5	13	1402	*Joint.*	
10	C 4 B 5	13	1155	*Joint.*	
11	C 4 B 5	12	1465	BRICK.	
12	C 4 B 5	12	1549	*Joint.*	
1	C 4 B 5·1	11	709	*Joint.*	751
2	C 4 B 5·1	11	541	*Joint.*	
3	C 4 B 5·1	13	989	*Joint.*	
4	C 4 B 5·1	13	765	*Joint.*	
1	C 4 B 5·2	11	933	*Joint.*	1412
2	C 4 B 5·2	11	1521	*Joint.*	
3	C 4 B 5·2	11	1465	*Joint.*	
4	C 4 B 5·2	11	1353	BRICK.	
5	C 4 B 5·2	11	1297	*Joint.*	
6	C 4 B 5·2	11	1941	*Joint.*	
7	C 4 B 5·2	11	2193	BRICK.	
8	C 4 B 5·2	11	1605	BRICK.	
9	C 4 B 5·2	13	427	*Joint.*	
10	C 4 B 5·2	13	1388	*Joint.*	

TABLE II. CONTINUED.

No. of Experiment.	Proportions of the Mixture by weight of C, Chalk, and B, Blue Clay.	Age of the Cement, in days.	Weight that tore asunder the Mass, in lbs.	The fracture took place in the	Average Adhesiveness, in lbs.
1	C 4 B 5·3	12	1199	BRICK.	1277
2	C 4 B 5·3	12	1388	BRICK.	
3	C 4 B 5·3	12	1332	BRICK.	
4	C 4 B 5·3	12	1113	BRICK.	
5	C 4 B 5·3	12	1113	BRICK.	
6	C 4 B 5·3	12	1514	BRICK.	
1	C 4 B 5·4	12	1584	BRICK.	1413
2	C 4 B 5·4	12	1328	BRICK.	
3	C 4 B 5·4	12	1493	*Joint.*	
4	C 4 B 5·4	12	1325	BRICK.	
5	C 4 B 5·4	12	1325	BRICK.	
6	C 4 B 5·4	12	1423	BRICK.	
1	C 4 B 5·5	12	1493	BRICK.	1453
2	C 4 B 5·5	12	1409	BRICK.	
3	C 4 B 5·5	12	1325	BRICK.	
4	C 4 B 5·5	12	1633	*Joint.*	
5	C 4 B 5·5	12	1528	BRICK.	
6	C 4 B 5·5	12	1325	*Joint.*	
1	C 4 B 5·6	11	1115	*Joint.*	987
2	C 4 B 5·6	11	641	*Joint.*	
3	C 4 B 5·6	11	1115	BRICK.	
4	C 4 B 5·6	11	1409	*Joint.*	
5	C 4 B 5·6	11	821	*Joint.*	
6	C 4 B 5·6	11	821	*Joint.*	

(186) On examining the contents of the foregoing Table with attention, and comparing it with the results of our former experiments, some anomalies appear. For example, mixture C 4 B 5·1, being an intermediate proportion between C 4 B 5 and C 4 B 5·2, if it had been equally well burned and equally well managed with these two, ought undoubtedly to have been stronger than the former of them; and amongst the nine mixtures experimented upon, it ought to have ranked the fifth in point of strength, instead of being the weakest of the whole. Moreover, in our last experiments, C 4 B 5 proved to be weaker than C 4 B 5·2, C 4 B 5·4, and C 4 B 5·5, whereas it ought to have been stronger than any of them, according to the conclusion drawn from our former experiments recorded in Articles 178 and 180, for it had then proved superior to C 3 B 4, which agrees nearly with mixture C 4 B 5·2 of our last experiments.

In these it was a great subject of regret to us, that we should have been so unfortunate in respect to the quality of our bricks, which now broke down under one-half, and sometimes even under one-third part only, of the average weights that were required to tear asunder the excellent bricks used in our first experiments.* Hence our last experiments afforded no criterion at all of the comparative strength of mixture C 4 B 5·3, and a very imperfect one of the two mixtures next in order in the Table.

More numerous experiments tried with better bricks, if we could procure them, would undoubtedly enable us to fix the comparative strength of every mixture with sufficient precision, and at the same time would reconcile the anomalies alluded to; for upon the whole, the results of the experiments already tried are in sufficient accordance with each other, to satisfy us that these anomalies do not arise from any irregularity, in the comparative strength of mixtures prepared and managed exactly in the same manner, but from the imperfections of our own manipulation. In fact, it is so difficult to mix, burn, and use, the same artificial cement mixture always equally well, that nothing but the average of a very great number of experiments can yield satisfactory results; but I was deterred from trying more numerous experiments for this purpose; partly from having no hope at the time of obtaining bricks stronger than the last, and partly from the consideration, that the experiments already tried having proved that our artificial cement after a short time becomes stronger than the strongest bricks, it was unnecessary, as far as brickwork was concerned, to attempt to prove more than had thus already been proved, namely, that it was stronger than strong enough.

FINAL DEDUCTION FROM THOSE EXPERIMENTS ON THE COMPARATIVE ADHESIVE STRENGTH OF OUR VARIOUS ARTIFICIAL CEMENT MIXTURES OF CHALK AND BLUE ALLUVIAL CLAY.

(187) Upon the whole, on comparing the results of all our experiments attentively, and weighing probabilities where their evidence was imperfect or contradictory, the superiority seemed to rest with C 4 B 5·5, and by reducing this proportion

---

* The weakest bricks now alluded to were marl bricks, of the very same earth as the strongest of the bricks that we had experimented upon before, made in the same field and under the superintendence of the same Master Brickmaker. On examining the fractures of these weak bricks, it appeared that the ingredients, namely, brick earth with a small proportion of chalk to colour it, had not been so well mixed as in the others; for small white lumps of imperfectly ground chalk were visible in many parts. This defect, which was scarcely perceptible in the fractured parts of the strong bricks, cannot be discovered by merely examining the outside.

to a more convenient form, it appeared that a mixture of 10 parts by weight of pure chalk, perfectly dry, with 13¾ parts, also by weight, of the blue alluvial clay of 1837 fresh from the Medway, would produce the strongest artificial cement that could be made by any combination of these two ingredients, and it had the advantage of not setting so quickly, either as the artificial cement prepared by us in 1830, or the natural cement produced from the pebbles of the Isle of Sheppy.

(188) After having discovered what very little dependence could be placed on the cohesive strength of bricks, it appeared desirable, in the event of further experiments on the same subject, to prepare what may be termed stone bricks, of some kind of stone that should be easily worked, and yet stronger in the cohesiveness of its particles, as opposed to a tearing force, than our best artificial cement. In order to ascertain what sort of stone would answer best, I therefore previously caused pieces of stone of various descriptions, two of each sort, to be cut to the same length and width as common bricks, but to more than double their depth, and to be prepared with four mortises, two on each side, one over the other, allowing 1¾ inch of solid matter above and below these holes, being a quarter of an inch more than in our brick experiments. On suspending each of these blocks to the triangle by the upper nippers, and attaching the scale board to them by the lower nippers, as shown in the annexed figure, and applying weights in the usual manner until they all successively broke down, the results inserted in the following Table took place.

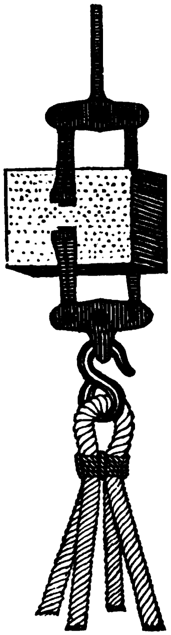


TABLE III. COMPARATIVE COHESIVENESS OF VARIOUS SORTS OF STONE.

Description of Stones experimented upon.	Weight in lbs. that tore them asunder, in Experiment		Average Cohesiveness, in lbs.
	No. 1.	No. 2.	
1. Portland Stone	2964	5045	4004
2. Cornish Granite..........	3741	3941	3841
3. Kentish Rag Stone........	3549	3997	3773
4. Yorkshire Landing........	3597	3688	3642
5. Craig Leith Stone	2103	2775	2439
6. Bath Stone..............	1549	1268	1408
7. Sound Chalk	323	623	473

Hence Portland appeared to possess the strongest cohesiveness of all those stones, and being easily worked, and also apparently of a favourable texture for uniting with cement, it seemed the most convenient sort of stone that we could use for further experiments of the nature before described, in which our bricks had failed.*

At this period, our experiments had been sufficiently numerous to enable us to lay down rules that may be very useful to the purchasers of cement.

FIRST. RULE FOR JUDGING WHETHER THE CEMENT SUPPLIED BY A MANUFACTURER IS IN A PROPER STATE FOR USE.

(189) The natural cements obtained from the same spot are not all equally good even if burned alike, and in Government Departments especially, where the lowest tender is generally accepted, cements much inferior to the terms of contract are sometimes offered. The mode of experimenting adopted by us at Chatham, affords a sufficiently correct criterion for judging whether the cement is in a proper state for use, that is, whether it is good, well burned and well preserved.

For this purpose, mix up the cement powder with water, and make four or five experimental balls of it, not exceeding an inch in diameter (47). Allow them to set with warmth and cool again, which in good but rather slow setting cement will require about half an hour, after which put two or three of them into a small basin of water. If they continue to set in this state, and become very hard in the course of a day or two, the cement is good. If on the contrary they do not become very hard in this time, both inside and out, whether previously kept in air or in water, the cement is not in a state fit for use, and should be rejected.

---

* In both trials with the Craig Leith stone, it was torn asunder horizontally according to the grain, opposite to the bottom of the lower mortise, as if it had been split by wedges. In respect to all the other stones, if the solid part above one of the mortises gave way, the fracture diverged upwards; if below, downwards, at rather an obtuse angle. Hence when two opposite mortises gave way, the original level surface of the stone above or below them was changed into a ridge in the centre, and reduced much narrower, so as to approximate to that form, towards the ends. The same sort of fracture was also exhibited by the bricks previously experimented upon by us, whenever they gave way. It may be remarked that the best of our bricks seemed not to be inferior to Portland stone in cohesive strength, since some of them bore more than 4000 lbs., although they had less solid matter beyond the mortises cut in them. But one cannot depend on the average strength of bricks, with so much confidence as on that of good stone.

SECONDLY. RULE FOR ASCERTAINING WHETHER CEMENT OF IMPROPER QUALITY HAS ORIGINALLY BEEN GOOD, BUT INJURED BY BECOMING STALE; OR WHETHER IT MAY NOT HAVE BEEN THE PRODUCE OF BAD CEMENT STONE, OR OF GOOD CEMENT STONE ADULTERATED AFTER CALCINATION.

(190) If the experimental balls, made as described in the last Article, will not set properly either in air or in water, the next point is to ascertain the cause of their failure. For this purpose burn the same balls in a crucible for two or three hours in a common fire-place, exposing them to a full red heat, until they cease to effervesce with acids (45). Then pound the calcined cement in a mortar till you reduce it to an impalpable powder, and mix it up once more into experimental balls with water. If the cement, after being thus reburned, should set well both in air and under water, it is a proof that it was originally good, but had been spoiled by exposure to air or damp.

(191) If on the contrary the cement, supplied by a manufacturer in a state unfit for the purposes of Practical Architecture, should not be improved by the process of reburning it, which completely restores the virtue not only of stale cement, if originally good, but also of stale lime, as was before explained (145), it is a proof that it has either been made of cement stone of such very bad quality as would not repay the expense of burning it, or if the produce of good stone, that it must have been adulterated, by mixing the calcined cement powder with earth or sand of the same colour, before it was casked up.* These two last cases cannot be discriminated in cement prepared for sale.

THIRDLY. RULE FOR JUDGING OF THE COMPARATIVE ADHESIVE STRENGTH OF DIFFERENT SORTS OF CEMENT.

(192) Having ascertained that the cements to be compared

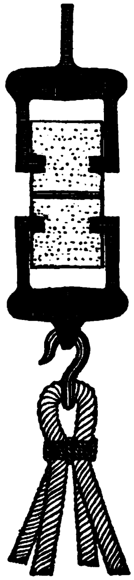
---

* Having at this time been requested to examine some cement supplied for the works in Chatham Dockyard, which the receiving Officers had rejected, I not only confirmed their opinion that it was unfit for use, because the experimental balls made of it would neither set in air nor in water; but as the same failure took place after reburning the cement, I assured them that in all probability it must have been adulterated, by mixing it with some dark coloured earth; for as one must give the person who supplied it credit for common sense, though not for the faithful execution of his contract, it is scarcely to be supposed, that he could have been foolish enough to burn a quantity of bad cement stone. I did not inquire the name of this person, as I rather wished not to know it. I also examined some other cement supplied for the use of the same Dockyard at the same time, by other manufacturers whose names were made known to me, and found it to be very good. This last was the same cement with which the Master Bricklayer of the yard had once set out 14 bricks from a wall (132).

together are in a serviceable state, by the simple process described in the preceding Articles, without which it is of no use to take any further trouble, two modes which have already been described offer themselves for judging of their comparative strength; first, the usual mode of setting out bricks from a wall, which I consider objectionable for the reasons stated in Article 183.

Setting aside the above, I know no method so good, and attended with so little trouble, as to prepare a breaking-down apparatus, such as has before been described, consisting of a scale board, planks, and weights, and a couple of pairs of nippers, to be used with a gyn or triangle, as shown in the figure to Article 179, which gyn might be dispensed with, if the cap of a large tressel, or some beam sufficiently strong for suspending the apparatus, were available for the same purpose.

But instead of using bricks, which we found to be so very precarious, I would recommend a number of pieces of Portland or Kentish rag stone, or of any other sound hard stone, each exactly 10 inches long, 4 inches broad, and about 4 inches deep, more or less, for this last dimension is of minor importance, to be prepared with mortises in the sides, each one inch wide and one inch deep, and from three-quarters to half an inch in height, to receive the nippers, after being cemented together in pairs, as shown in the annexed figure, which mortises should have at least 2½ inches of solid stone above and below them. The rectangular surface of each stone, where the cement is to be applied, should be roughened every where to the depth of about an eighth of an inch, by furrowing it all round with a half-inch chisel, and dotting it in the centre by cutting a number of small holes into it with a mason's pick or point, and all the surfaces should be carefully compared, to see that they are as nearly alike as possible. Ten such stones should be provided for each sort of cement that is to be experimented upon, that is, 20 for 2 sorts, and 30 for 3 sorts of cement, which must be cemented together in pairs, and left 10 days for the cement to set. At the end of this period let them all be broken down by successive weights, which will allow 5 trials for each sort of cement.



Probably less than 10 days might suffice for a fair trial of comparative strength, and possibly also if the period of trial were increased to 2, 3, 4, or more months, the slower setting cements might gain upon that which was the victor of the ten days. But however that may be, there can be no doubt that when cements, all of good quality and each ten days old, are tried against each other, that which proves to be the strongest of the whole, whether it should be able to retain its superiority at a much greater age or not, cannot fail to be excellent. The small stone bricks here described may be used for years, if cleaned after each trial, by making the nippers and mortises fit rather tightly, and by tying small strings round the nippers to keep them and the stones together, and prevent them from falling when the cement joint is fractured.

(193) To ascertain more precisely the effect which sand produces upon the adhesiveness of cement, which we had long known to be unfavourable, I afterwards caused three little brick masses to be connected by net cement of mixture C 4 B 5, and three others to be connected by a mixture of the same cement with clean sharp sand in equal parts, by measure; and in order to compare their adhesiveness with that of old chalk lime mortar also, I caused some little masses to be cut out of the best brick walls built with mortar of this description, that I could find within Chatham Lines, and having prepared these small specimens of brickwork also, with proper mortises to receive the nippers, the whole were torn asunder in the usual manner, by successive weights, as stated below.

TABLE IV. COMPARATIVE ADHESIVENESS TO STONE, OF NET CEMENT, OF CEMENT MIXED WITH SAND, AND OF COMMON CHALK LIME MORTAR.

No. of the Experiment.	Whether with Cement, or with Chalk Lime Mortar.	Age in Days, or Years.	Weight that tore the joint asunder, in lbs.	Average Adhesiveness, in lbs.
1	Net Cement	11 days	1241	1092
2	Net Cement	17 days	1003	
3	Net Cement	17 days	1031	
1	Cement and Sand..	11 days	205	225
2	Cement and Sand..	11 days	257	
3	Cement and Sand..	17 days	313	
1	Chalk Lime Mortar	30 years	334	155
2	Chalk Lime Mortar	30 years	64	
3	Chalk Lime Mortar	30 years	75	
4	Chalk Lime Mortar	30 years	47	
5	Chalk Lime Mortar	30 years	205	
6	Chalk Lime Mortar	30 years	204	

(194) Hence it appears that net cement is more than four times as strong at the same age, as the customary mixture of cement and of sand in equal parts by measure, which is in common use in and near the metropolis. Mr. Brunel was therefore quite right, in employing only net cement in the arches of his tunnel, and I think that the same ought to be done in all arduous works, where the sudden downfal of an arch is to be guarded against, as in tunnelling in bad soil, even in dry situations, where an overwhelming inrush of water from above is not to follow. At the same time, in all other situations, where no extraordinary risk is to be apprehended, as in building wharf walls, locks of canals, &c., with cement, the addition of an equal volume of sand is not to be reprobated; because this proportion, whilst it renders the cement mortar cheaper, is not sufficient to take away its hydraulic properties, and even when only 17 days old, it appears from those experiments to equal if not to exceed the strength of the best chalk lime mortar of 30 years of age. I conceive it probable, that if tried at a greater age, the cement mortar would exceed the strength of the chalk lime mortar in a five-fold ratio; for I know that blasting has been required to separate old brickwork built with the former, whilst the latter has no strength at all in water (15), and so little in air, that several of the chalk lime mortar joints of brickwork, of the age before mentioned, separated merely on being handled, after we had cut them out of the walls alluded to for the sake of experiment, without any weights being applied to them, which circumstance I do not consider as a proof that the strength of those joints was absolutely null; because they may have been shaken and weakened in the process of cutting out the bricks round them, which would not have injured old cement at all. For we had before observed that cement was much less brittle than bricks (177).

(195) Having prepared a number of stone bricks, as they may be termed, of various sorts of stone, of the dimensions and description explained in Article 192, we cemented them together in pairs by mixture C 4 B 5, and on breaking them down, generally at the end of 11 days afterwards, we obtained the results contained in the following Table.

TABLE V. COMPARATIVE ADHESIVENESS OF CEMENT TO BRICKS, AND TO VARIOUS SORTS OF STONE.

Bricks or sort of Stone used.	When tried.	No. of the Experiment.	Age of the Cement, in days.	Weight that tore the joint asunder, in lbs.	Average Adhesiveness, in lbs.
Bricks..........	From Dec. 1836, to Feb. 1837, incl.	12 in all	11 to 13	See Table II.	1359
Bath Stone......	April 17th, 1837	1	11	961	1103
	” ”	2	11	1031	
	” „	3	11	1010	
	„ 28th	4	11	1086	
	” ”	5	11	1429	
Cornish Granite..	March 28th	1	11	657	900
	” ”	2	11	520	
	” „	3	11	895	
	April 29th	4	11	1310	
	” ”	5	11	1116	
Portland Stone ..	April 17th	1	11	779	856
	” ”	2	11	954	
	” „	3	11	975	
	„ 28th	4	11	757	
	” ”	5	11	813	
Yorkshire Landing Stone........	Dec. 31st, 1836	1	12	1101	823
	April 17th, 1837	2	11	485	
	” ”	3	11	604	
	” „	4	11	1010	
	„ 28th	5	11	596	
	” ”	6	11	1142	
Kentish Rag Stone	April 28th	1	11	1373	1349
	” ”	2	11	1240	
	” ”	3	11	2157	
	” ”	4	11	764	
	” ”	5	11	1212	
Craig Leith Stone	May 13th	1	11	876	855
	” ”	2	11	764	
	” ”	3	11	596	
	” ”	4	11	1093	
	” ”	5	11	946	
Cornish Granite, polished......	May 19th	1	11	1100	928
	” ”	2	11	757	

(196) In respect to all the experiments but one with the small stone bricks, part of the cement was burned in March or in the beginning of April, part towards the end of that month, and part in the beginning of May; and the stones, though all accurately squared to the same gage, were prepared by different masons, and some were much smoother than others, which we ought to have guarded against beforehand, but did not remark the difference until after the first 26 pairs of stones had been experimented upon. Considering therefore

that these two causes combined, namely, the possible difference in the adhesive strength of the cement, and the known inequality in the state of the surfaces of the stones connected by it, but especially the latter, might have given rise to the principal irregularities in the above results, we resolved, in order to determine this point with more precision, to polish the surfaces of the same pieces of Cornish granite used in experiments 4 and 5, and to cement them together again by the same mixture, and to break them down once more in the usual manner, after the cement should have attained the proper age. To our great surprise, the results of these new experiments, which appear as the last in the above Table, prove that the cement adhered to the polished surfaces, with nearly as much energy as it had done to the same pieces of granite when they were rough, for its average adhesiveness to the polished granite in these two experiments is measured by 928 ℔s., whilst its average adhesiveness to the same pieces of granite when rough, as determined by the two experiments Nos. 4 and 5, tried on the 29th of April, was 1213 ℔s. Moreover, the average adhesiveness of the cement to the polished granite exceeded by one-half its average adhesiveness to the rough granite, in three out of the first five experiments, tried with the granite in a rough state. These discrepancies are very curious, but the difference in the state of the cement may have caused them.

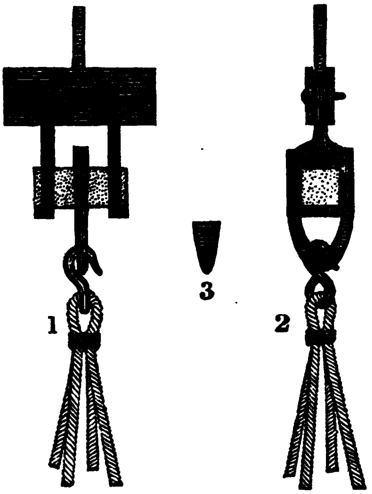
It is also to be remarked, that the adhesiveness of cement to Kentish rag stone, except in one experiment out of five, is superior; whilst its adhesiveness to Bath stone in four experiments out of five, to Yorkshire landing stone in three experiments out of five, and to Cornish granite in three experiments out of six, was not much inferior to its average adhesiveness to bricks. In the remaining experiments with these stones, the comparative adhesiveness of cement was considerably less; but so far as regarded the Kentish rag stone in particular, we ascertained that the great inferiority of adhesiveness in experiment No. 4 must undoubtedly have proceeded from the cement having been mixed by the workmen, in that experiment, in a much more fluid state than in most of the others, which happening to observe at the time, I caused the circumstance to be noted in the journal of our experiments, and the effect to be watched and recorded afterwards, when all the little masses of that stone were broken down. Never having particularly attended to this circumstance before, I conceive it very probable, that in our former experiments recorded in Table II., Article 185, some of the most glaring inequalities in the adhesive strength of our various cement mixtures, as for example, experiment No. 9 with mixture C 5 B 5·2, in which the joint broke down under 427 lbs., though the average strength of nine other experiments tried with the same mixture exceeded 1400 lbs., may have proceeded from the same cause, namely, the too great fluidity of the cement; for we always measured 18 cubic inches of cement powder for each joint, and if the men happened to pour a little too much water over any such portion, we did not correct it properly, by immediately adding more cement powder as we might have done, because we could not afford to waste our cement, and therefore some few of our joints were much thinner than the generality of others.

(197) Upon the whole, I do not consider the experiments recorded in the preceding Table to be absolutely conclusive, as to the comparative adhesiveness of the same species of cement to various sorts of stone, to determine which with sufficient precision, much more numerous experiments would be desirable. It may however be inferred from them, that the adhesiveness of cement to the least congenial sort of stone is more than one-half and from thence to two-thirds and nearly three-fourths of its adhesiveness to bricks, but that its adhesiveness to some sorts, such as the Kentish rag stone, may fairly be considered equal to its adhesiveness to bricks, and it appears to adhere to some of the hardest stones with greater energy than to much softer ones; and so far as regards the former, our few experiments with the Cornish granite seem to prove, that the state of the surface, whether more or less smooth, is of very little importance, so that in building with stone and cement, every mason may be allowed to dress the beds of the stones as he pleases, provided that he adhere to some general rule laid down in the Architect's or Engineer's Specification.

(198) On comparing these last experiments with those previously recorded in Table IV., Article 193, a fact of the greatest importance is fully proved, namely, that *net cement attaches itself to the most refractory sort of stone, with five times as much adhesive force, in eleven days, as the best chalk lime used in brickwork is capable of attaining in thirty years.*

(199) At this period, as the small artificial stones in the form of square prisms, made by us for experiment in the manner described in from Article 137 to 144 inclusive, which were all kept in a dry apartment, had attained a sufficient age, generally more than 12 months, to enable us to judge of their comparative strength with some degree of confidence, we determined to break them down by weights applied to

the middle of each when supported at both ends, by a couple of iron stirrups, at the clear distance of 3 inches apart. Before the prism was placed upon these bearers, another iron stirrup inverted was passed over one end as far as the middle of the prism, upon the upper surface of which the top of this stirrup rested, whilst the bottom of the same stirrup being open, we hooked on a very light scale board to it for containing the weights, which were gradually increased till fracture took place. The upper iron work of this apparatus was suspended to the gyn, as in our former experiments. The surface of the two stirrups that supported each prism was flat, but that part of the inverted stirrup, which pressed upon the top of it, was in the form of a blunted knife edge.



The annexed figures 1 and 2 represent one of these small artificial stones, or square prisms, about to be experimented upon by this apparatus, the former in side, the latter in end elevation, whilst figure 3 shows the section of the knife edge part of the inverted stirrup before mentioned, on a larger scale.

This mode of proceeding is on the principle that had previously been adopted by General Treussart, one of the French writers before alluded to (4), in his elaborate course of experiments on common and hydraulic mortars, and is perhaps the best that could be used for determining their resistance or comparative strength, but not their comparative adhesiveness to bricks and different sorts of stone.*

(200) Of the two Tables hereafter annexed, relating to these experiments, the first, which is numbered Table VI., refers chiefly to the artificial stones made of gravel, marked by the letter G, coarse sand marked by the letter S, and fine sand marked by a small s, which were described in from Article 138 to 143 inclusive. Some few experiments only

---

* General Treussart's experimental prisms were 5 centimetres square, and the distance between their points of support 10 centimetres, which dimensions are very nearly equal to 2 English inches square, and 4 inches between the bearings.

in the same Table, in which the sand is not specially divided into fine and coarse, imply that the sort of sand used was of the quality proper for making mortar.

The whole of the artificial stones made by us were not forthcoming, some of them having split, or having been broken by accident, or having crumbled into dust from excess of sand, on being merely handled: others, though well adapted for setting in air, having gone to pieces from being put under water in small tin troughs too soon, that is, within 15 hours after having been made, which none of them, not even those made of that very powerful lime the blue lias, nor of the still more powerful natural or artificial cements could bear, unless the proportion of sand were reduced so low, as not to exceed the lime or cement powder in much more than a two-fold ratio by measure, which does not come within the usual definition of a concrete at all, and which would be far too expensive to be used as an artificial stone. In consequence of the failures now alluded to, which occurred at the commencement of our experiments upon those little artificial stones, we allowed all those made afterwards, which we wished to try under water, to remain at least 16 days, and some of them even 32 days or more in air, previously to immersion, which enabled them to set to such a degree, that most of them seemed proof against the further action of the water, which, however, was any thing but violent, as they were kept in small tin cases not much larger than the prisms themselves, and the water was not changed, but only made good when lessened by evaporation. The precise number of days previously to immersion are noted opposite to each, in one of the columns of the following Table, it being understood that where no number is entered opposite to any artificial stone, it was not put under water at all.

(201) From the experiments recorded in Table VI., I should have been inclined to suppose that even chalk lime concrete, if kept dry by means of coffer-dams or otherwise, until it had set to a certain degree, and if protected afterwards from the action of water in mass, would not lose a certain moderate degree of hardness, whether used for the foundation or the backing of the wall of a wharf or wet dock; but as chalk lime mortar, made and used with equal care, is well known to be much inferior in strength to Halling lime mortar, and as I myself never saw any wharf wall laid open, in which the backing, if originally built with chalk lime mortar, was not in a state of pulp (15), I should be very sorry to try the

experiment of using chalk lime concrete on a great scale in damp situations. In respect to our experimental artificial stones made with Halling lime, it will be observed that the same mixtures which had been kept under water, were generally stronger than those which had been kept in air. With regard to blue lias lime, considering the many well authenticated reports of its very strong hydraulic properties, we did not think it worth while to expose any of the concretes formed with it to the action of water.

(202) Table VII. refers to those artificial stones or concretes mentioned in Article 144, in which the same sort of screened Thames ballast only was used, in combination with various sorts of limes and cements, and which, from this circumstance, it seemed best to keep separate from the former, although the ballast may have been very nearly similar to some of the mixtures of gravel and of coarse and fine sand, which are described in Table VI. None of our small artificial stones, made with the screened Thames ballast, were exposed to the action of water.

TABLE VI. COMPARATIVE RESISTANCE OF EXPERIMENTAL ARTIFICIAL STONES, COMPOSED OF DIFFERENT SORTS OF LIME OR CEMENT, MIXED WITH VARIOUS PROPORTIONS OF GRAVEL OR SAND, OR BOTH.

When made.	No. of the Experiment.	Quick-lime Powder or Cement Powder by measure, mixed with G Gravel, S coarse Sand, and s fine Sand.	Whether made with hot or cold water.	If kept under water, age when immersed, in days.	Age when broken down, in days.	Proportion of Lime or Cement to the		Resistance measured by the breaking weight, in lbs.
						Sand only.	Gravel and Sand.	
1836.								
Feb. 2	1	Chalk Lime 1, Sand 3¼ ..	cold	19	432	1 to 3¼	....	48
Mar. 10	2	„ 1, Sand 3¼ ..	„	..	396	.. 3¼	....	109
„	3	„ 1, Sand 3¼ ..	„	..	396	.. 3¼	....	98
Feb. 6	4	„ 1, G 3 S 1 s ½	„	..	428	.. 1½	1 to 4½	87
Jan. 15	5	„ 1, G 6	hot	18	457	....	.. 6	crumbled.
„	6	„ 1, G 4 s 2....	„	18	457	.. 2	.. 6	67
18	7	„ 1, G 4 s 2....	cold	33	454	.. 2	.. 6	69
„	8	„ 1, G 4 s 2....	„	..	463	.. 2	.. 6	60
15	9	„ 1, G 5 s 2....	hot	18	457	.. 2	.. 7	48
19	10	„ 1, G 3 S 2 s 2	„	..	446	.. 4	.. 7	20
15	11	„ 1, G 6 s 2....	„	18	457	.. 2	.. 8	56
18	12	„ 1, G 6 s 2....	cold	..	463	.. 2	.. 8	94
Feb. 6	13	„ 1, G 4 S 2 s 2	„	..	428	.. 4	.. 8	27
Jan. 19	14	„ 1, G 4 S 2 s 2	hot	..	446	.. 4	.. 8	67
„	15	„ 1, G 6 S 2 s 1	„	32	446	.. 3	.. 9	50
„	16	„ 1, G 5 S 3 s 1	„	..	446	.. 4	..10	39
Mar. 18	17	„ 1, G 6 S 2 s 2	„	..	388	.. 4	..10	76
„	18	„ 1, G 6 S 2 s 2	„	..	388	.. 4	..10	71
21	19	„ 1, G 6 S 2 s 2	„	..	385	.. 4	..10	crumbled.
Jan. 18	20	„ 1, G 7 s 3....	„	..	463	.. 3	..10	39

TABLE VI. CONTINUED.

When made.	No. of the Experiment.	Quick-lime Powder or Cement Powder by measure, mixed with G Gravel, S coarse Sand, and s fine Sand.	Whether made with hot or cold water.	If kept under water, age when immersed, in days.	Age when broken down, in days.	Proportion of Lime or Cement to the		Resistance measured by the breaking weight, in lbs.
						Sand only.	Gravel and Sand.	
May 9	1	Halling Lime 1, Sand 3 ..	cold	..	342	1 to 3	....	179
,,	2	,, 1, Sand 3 ..	,,	..	342	.. 3	....	83
Feb. 1	3	,, 1, Sand 3½..	,,	20	433	.. 3½	....	211
Jan. 21	4	,, 1, G 3 S 1 s ½	,,	..	444	.. 1½	1 to 4½	57
19	5	,, 1, G 3 s 2 ..	hot	..	462	.. 2	.. 5	87
15	6	,, 1, Sand 6 ..	,,	36	457	.. 6	....	197
,,	7	,, 1, G 6......	,,	18	457	....	.. 6	67
Feb. 6	8	,, 1, G 6......	cold	..	444	....	.. 6	56
Jan. 15	9	,, 1, G 4 s 2 ..	hot	18	457	.. 2	.. 6	209
18	10	,, 1, G 4 s 2 ..	cold	33	454	.. 2	.. 6	142
15	11	,, 1, G 5 s 2 ..	hot	18	457	.. 2	.. 7	151
,,	12	,, 1, G 5 s 2 ..	,,	36	457	.. 2	.. 7	69
18	13	,, 1, G 5 s 2 ..	cold	..	463	.. 2	.. 7	120
19	14	,, 1, G 4 S 2 s 2	hot	..	462	.. 4	.. 8	70
21	15	,, 1, G 4 S 2 s 2	cold	..	444	.. 4	.. 8	86
15	16	,, 1, G 6 s 2 ..	hot	18	457	.. 2	.. 8	132
18	17	,, 1, G 6 s 2 ..	cold	32	454	.. 2	.. 8	76
,,	18	,, 1, G 6 s 2 ..	,,	..	463	.. 2	.. 8	70
19	19	,, 1, G 5 S 3 s 1	hot	32	453	.. 4	.. 9	165
,,	20	,, 1, G 6 S 2 s 1	,,	32	453	.. 3	.. 9	183
15	21	,, 1, G 7 s 2 ..	,,	18	457	.. 2	.. 9	116
Feb. 22	22	,, 1, G 6 S 2 s 2	,,	..	412	.. 4	.. 10	76
Jan. 15	23	,, 1, G 7 s 3 ..	,,	18	457	.. 3	.. 10	132
18	24	,, 1, G 7 s 3 ..	cold	33	454	.. 3	.. 10	64
15	25	,, 1, G 8 s 3 ..	hot	18	457	.. 3	.. 11	crumbled.
,,	26	,, 1, G 8 s 3 ..	,,	18	457	.. 3	.. 11	84
19	27	,, 1, G 8 s 3 ..	cold	32	453	.. 3	.. 11	48
April 30	1	Blue Lias Lime 1, G 4⅞ s 1⅛	hot	..	352	1 to 1⅛	1 to 6	188
,,	2	,, 1, G 4⅞ s 1⅛	,,	..	361	.. 1⅛	.. 6	39
,,	3	,, 1, G 5 s 2..	,,	..	345	.. 2	.. 7	118
,,	4	,, 1, G 5 s 2..	,,	..	361	.. 2	.. 7	136
,,	5	,, 1, G 6 S 2 .	,,	..	345	.. 2	.. 8	111
,,	6	,, 1, G 6 S 2 .	,,	..	361	.. 2	.. 8	131
,,	7	,, 1, G 7 s 2..	,,	..	345	.. 2	.. 9	102
May 9	1	Rosehill Lime 1, Sand 2 ..	hot	..	342	1 to 2	....	188
,,	2	,, 1, Sand 2 ..	cold	..	342	.. 2	....	210
		Sheppy & Harwich Cements, mixed.						
Mar. 21	1	Francis's .. 1, G 1½ S 1 s 1	hot	..	385	1 to 2	1 to 3½	118
,,	2	,, 1, G 2 S 1 s 1	,,	..	385	.. 2	.. 4	48
,,	3	,, 1, G 4 S 1 s 1	,,	..	385	.. 2	.. 6	102
,,	4	,, 1, G 3 S 2 s 2	,,	..	385	.. 4	.. 7	24
		Artificial Cement.						
Mar. 21	1	(C 5 B 2) .. 1, G 1½ S 1 s 1	hot	..	385	1 to 2	1 to 3½	20
,,	2	,, 1, G 4 S 1 s 1	,,	..	385	.. 2	.. 6	27
Jan. 26	3	,, 1, G 4 S 2 s 2	,,	..	439	.. 4	.. 8	55
,,	4	,, 1, G 4 S 2 s 2	,,	..	439	.. 4	.. 8	48
,,	5	,, 1, G 5 S 2 s 2	,,	..	439	.. 4	.. 9	52

TABLE VI. CONTINUED.

When made.	No. of the Experiment.	Quick-lime Powder or Cement Powder by measure, mixed with G Gravel, S coarse Sand, and s fine Sand.	Whether made with hot or cold water.	If kept under water, age when immersed, in days.	Age when broken down, in days.	Proportion of Lime or Cement to the Sand only.	Proportion of Lime or Cement to the Gravel and Sand.	Resistance measured by the breaking weight, in lbs.
		Artificial Hydraulic Lime. 1st sort.						
Feb. 3	1	(C 5 B 1)....1, G 3 S 2 s 2	hot	18	431	1 to 4	1 to 7	97
„	2	„ 1, G 3 S 2 s 2	„	..	431	.. 4	.. 7	69
„	3	„ 1, G 4 S 2 s 2	„	18	431	.. 4	.. 8	83
„	4	„ 1, G 4 S 2 s 2	„	..	431	.. 4	.. 8	62
„	5	„ 1, G 6 s 2 ..	„	18	431	.. 2	.. 8	132
„	6	„ 1, G 6 s 2 ..	„	..	431	.. 2	.. 8	104
„	7	„ 1, G 5 S 3 s 1	„	18	431	.. 4	.. 9	90
„	8	„ 1, G 5 S 3 s 1	„	..	431	.. 4	.. 9	86
		Artificial Hydraulic Lime. 2nd sort.						
Feb. 4	1	(C 6 B 1)....1, G 3 S 2 s 2	hot	17	430	1 to 4	1 to 7	86
„	2	„ 1, G 3 S 2 s 2	„	..	430	.. 4	.. 7	125
„	3	„ 1, G 4 S 2 s 2	„	17	430	.. 4	.. 8	64
„	4	„ 1, G 4 S 2 s 2	„	..	430	.. 4	.. 8	97
„	5	„ 1, G 6 s 2 ..	„	17	430	.. 2	.. 8	83
„	6	„ 1, G 6 s 2 ..	„	..	430	.. 2	.. 8	101
„	7	„ 1, G 5 S 3 s 1	„	17	430	.. 4	.. 9	58
„	8	„ 1, G 5 S 3 s 1	„	..	430	.. 4	.. 9	65
		Artificial Hydraulic Lime, 3rd sort.						
Feb. 5	1	(C 7 B 1)....1, G 3 S 2 s 2	hot	16	429	1 to 4	1 to 7	109
„	2	„ 1, G 3 S 2 s 2	„	..	429	.. 4	.. 7	97
„	3	„ 1, G 4 S 2 s 2	„	16	429	.. 4	.. 8	76
„	4	„ 1, G 4 S 2 s 2	„	..	429	.. 4	.. 8	90
„	5	„ 1, G 6 s 2 ..	„	16	429	.. 2	.. 8	90
„	6	„ 1, G 6 s 2 ..	„	..	429	.. 2	.. 8	125
„	7	„ 1, G 5 S 3 s 1	„	16	429	.. 4	.. 9	55
„	8	„ 1, G 5 S 3 s 1	„	..	429	.. 4	.. 9	98

TABLE VII. COMPARATIVE RESISTANCE OF EXPERIMENTAL ARTIFICIAL STONES, COMPOSED OF DIFFERENT SORTS OF LIME OR CEMENT, MIXED WITH VARIOUS PROPORTIONS OF SCREENED THAMES BALLAST.

When made.	No. of the Experiment.	Proportion of Quick-lime Powder, or Cement Powder, and Ballast, by measure.	Experiment, No. 1. Age, in days.	Experiment, No. 1. Breaking weight, in lbs.	Experiment, No. 2. Age, in days.	Experiment, No. 2. Breaking weight, in lbs.	Average resistance, in lbs.
1836.							
July 30th	1	Chalk Lime .. 1, Ballast 3	240	47	270	60	53
„	2	„ 1, „ 4	240	106	270	95	100
„	3	„ 1, „ 5	240	142	270	126	134
July 29th	4	„ 1, „ 6	241	89	271	109	99
„	5	„ 1, „ 7	241	93	271	94	93

TABLE VII. CONTINUED.

When made.	No. of the Experiment.	Proportion of Quick-lime Powder, or Cement Powder, and Ballast, by measure.	Experiment, No. 1.		Experiment, No. 2.		Average resistance, in lbs.
			Age, in days.	Breaking weight, in lbs.	Age, in days.	Breaking weight, in lbs.	
July 29th	6	Chalk Lime .. 1, Ballast 8	241	61	271	49	55
„	7	„ 1, „ 9	241	47	271	39	43
„	8	„ 1, „ 10	241	35	271	36	35
July 30th	1	Halling Lime 1, Ballast 3	240	169	270	175	172
„	2	„ 1, „ 4	240	178	270	133	155
„	3	„ 1, „ 5	240	159	270	112	135
„	4	„ 1, „ 6	240	75	270	..	75
„	5	„ 1, „ 7	240	61	270	84	72
„	6	„ 1, „ 8	240	69	270	70	69
„	7	„ 1, „ 9	240	61	270	77	69
„	8	„ 1, „ 10	240	79	270	54	66
Aug. 6th	1	Blue Lias Lime 1, Ballast 3	234	75	263	87	81
1st	2	„ 1, „ 4	239	40	268	..	40
„	3	„ 1, „ 5	239	72	268	68	70
„	4	„ 1, „ 6	239	138	268	100	119
„	5	„ 1, „ 7	239	108	268	53	80
„	6	„ 1, „ 8	239	47	268	44	46
„	7	„ 1, „ 9	239	56	268	52	54
„	8	„ 1, „ 10	239	47	268	40	43
		Sheppy & Harwick Cements, mixed.					
Aug. 1st	1	Francis's .... 1, Ballast 2	239	124	268	143	133
..	2	„ 1, „ 3	239	110	268	108	109
6th	3	„ 1, „ 4	234	80	263	54	67
..	4	„ 1, „ 5	234	47	263	20	33
..	5	„ 1, „ 6	234	32	..	..	32
..	6	„ 1, „ 7	234	16	..	..	..
..	7	„ 1, „ 8	234	Accidentally broken.			
..	8	„ 1, „ 9	234	Crumbled into dust.			
..	9	„ 1, „ 10	234				

(203) It will be observed that the experiments in Table VI., and those in Table VII., are rather inconsistent with each other. In the former, all our concretes made with chalk lime were very much inferior to those made with Halling lime, not only under water, as might be expected, but in air also; whereas in the latter, the chalk lime concretes were generally very little inferior to those of Halling lime. Besides which, it might be inferred from both of these Tables, that the blue lias or Aberthaw lime was rather inferior in strength to the Halling lime. And it might also be supposed from Table VII. in particular, that the blue lias lime forms a stronger concrete with six times its volume of gravel and sand, than with any smaller proportion of the same ingre-

dients. The first of these conclusions, as to the superiority of the Halling lime over the blue lias, is in direct contradiction to experience; and the second, as to the quantity of sand that this lime will bear, is in contradiction to my own observation, as well as to the experience of Captain Savage, who used blue lias lime not only at the cobb or pier of Lyme Regis, which was built by tide-work (26), but at Hobbs' Point, near Pembroke, in a much more difficult work executed by the diving bell, which will be noticed in the Appendix. We therefore could not help doubting the accuracy of these conclusions; and afterwards we discovered that the usual mode of making concrete in England, adopted in our first experiments, was not calculated to yield an accurate estimate of the comparative resistance of artificial stones formed with different sorts of lime.

(204) The mode of proceeding now alluded to as being objectionable, is the same that has been approved by all our British Architects for making concrete for foundations, and which has more recently been adopted by Mr. Ranger in making his artificial stones, in which he has altered nothing in the former practice, except by substituting boiling water instead of cold. For this last purpose, I now consider the system of working with quick lime fresh from the kiln to be erroneous. Though reduced to a fine powder, and notwithstanding the use of hot water, both of which expedite the slaking, some small portions or particles of lime, being always more sluggish than others, will not slake until the greater part of the mass of the moistened quick-lime powder shall have undergone that process. But all calcined calcareous stones swell in slaking, except cement. Hence, after the artificial stone moulded in the usual manner has begun to set, owing to the slaking of the greater portion of the lime with which it has been formed, the more refractory portions of the same lime, in slaking afterwards, have a tendency to split the artificial stone, or to produce cracks at the surface. But although some of our small artificial stones, consisting of blue lias lime mortar and concrete, had gone to pieces from this cause, namely, the mortar alluded to in Article 26, and some concretes also made in 1836, which are recorded in the journal of our operations for that year, as having been made but destroyed afterwards, from proving imperfect; and although in respect to the mortar in particular, a remark had been entered in the same journal at the time, that the lime of which it was made appeared to be imperfectly slaked; yet such is the power of habit, that it never occurred to me that

the customary mode of making concrete in England was objectionable, until I had tried the following experiment.

(205) From the circumstance, so often remarked by me, that the strength of cement is much impaired by adding sand to it, and that the blue lias lime, which approaches nearer to cement in its water-setting properties than any other of our English limes, in like manner cannot bear so much sand as any of the weaker hydraulic limes or common lime, it occurred, that as net cement is much stronger than cement mortar, so the blue lias lime, net or mixed with water alone, might in like manner be stronger than the mortars made with the same lime and sand. I had also remarked, in reading the experiments of General Treussart, and of M. Vicat, in France, that the former had found, in some cases though not in all, that the hydrates of several hydraulic limes, experimented upon by him, were stronger than the mortars of the same limes mixed with sand, whilst the latter stated that small square prisms or cubes of common lime of the same quality as our English chalk lime, mixed with water alone, were much stronger than the mortars of the same sort of lime. Before I commenced my own researches, I should not only have considered M. Vicat's opinion to be quite erroneous, but I should have doubted the correctness of those statements of General Treussart, which were at variance with the general opinion of practical men in this country, who all agree in believing the mortar of every lime to be much stronger than the hydrate or putty of the same lime. But after having tried the experiments with cement and small artificial stones, that have been recorded in the foregoing parts of this Treatise, I became disposed to place confidence in the results of those experiments of General Treussart, which I should otherwise have considered paradoxical, and though not equally inclined to assent to M. Vicat's opinion, yet I felt that I was neither justified in adopting or rejecting the one or the other, without subjecting both to the test of further experiment.

I therefore proceeded to make some small artificial stones of the hydrates of blue lias as well as of chalk lime, in the same little moulds and by the same process before described (137 and 138), mixing the quick-lime powder with water whilst fresh from the kiln, and putting it into the mould immediately, and allowing it to heat there. This process, proper for cement only, but which as applied to concretes made of any sort of lime, mixed with a certain excess of gravel and sand, does not always develop its injurious tendency, proved to be quite inapplicable to net lime mixed with water alone; for no sooner had the lime putty or paste, introduced moist into the mould, begun to slake with heat, than it violently burst to pieces. I therefore afterwards allowed the lime paste to go through the process of heating, swelling, and bursting or cracking first, and mixed it up again with more water before putting it into the mould. Even on taking this precaution with the blue lias lime, it always split some time afterwards, unless we allowed several hours to intervene between the slaking and the moulding. For example, the first artificial stone or small square prism of blue lias lime, which I attempted to form one Saturday afternoon, split into three pieces in the course of an hour, though it was formed of lime paste, which had been allowed to become perfectly cool, after having been slaked with great heat in a basin just before. I therefore broke it down again and remixed it with more water, and remoulded it that same evening. On inspecting it on the Monday morning following, I found that this second attempt had also failed, for a large fragment of this new prism had split off during the interval. Though the lime at this time had set into a hardish substance, I caused it to be scraped or pared down into very thin slices by a knife, and then pounded in a mortar, and remixed with an additional quantity of water, and moulded a third time, after which it set without splitting, and at the end of 14 days from its being first mixed, but only 12 days from its being finally remoulded, we subjected it to the same breaking apparatus by which we had acted upon the small artificial stones which form the subject of Tables VI. and VII.; and to our great surprise, it required a weight of 328 ℔s. to break it down, whereas the same lime mixed as a concrete with six times its volume of gravel and sand, as recorded in Table VI., bore only 188 ℔s., though nearly a year old, and when mixed with 6 times its volume of screened Thames ballast as in Table VII., it bore only 119 ℔s., though nearly eight months old; but as other artificial stones afterwards made by us of the same hydrate or lime putty, did not evince the same extraordinary degree of strength, we cannot draw any inference from this remarkable but solitary experiment.

(206) On afterwards trying similar experiments with small artificial stones, some made of chalk lime putty, and others of chalk lime mortar, I found, contrary to M. Vicat's opinion, that the resistance of the hydrates, to a breaking or crushing weight, was inferior to that of the mortars.

(207) It may, however, perhaps be admitted as an axiom

in Practical Architecture, that whether the strength of any lime be diminished by the addition of sand, which applies to cement, and from General Treussart's experiments, probably to some of the hydraulic limes also; or whether it be increased by the addition of sand, which is believed to be the case with common limes; that the peculiar mode of slaking and using each lime, which produces the strongest hydrate when mixed with water alone, will also produce the strongest mortar or concrete of the same lime, when mixed with the most suitable proportion of sand and gravel also, in addition to water. Hence I am now of opinion, from considering the results of our more recent experiments, that the blue lias lime used in making our small artificial stones in 1836, should have been allowed not merely to slake with water and cool again, but to slake thoroughly, and for several hours, previously to mixing it with the gravel and sand, instead of mixing the ingredients immediately, and allowing the lime to heat in the mould and cool again, without disturbing it afterwards. There must have been a tendency in the lime of all these little artificial stones to crack, after the greater part of it was set, which process is extremely strong in the hydrates, but, as I said before, is checked in concretes, by the interposition of gravel and sand, in proportion to the quantity of those ingredients. But although when thus checked it may not be powerful enough to split the small artificial stones to pieces, or even to crack them at the surface, I have no doubt that the same action, however diminished, must tend to produce internal defects, and consequently a certain degree of weakness.

(208) Although common limes, which slake much more quickly and readily than the blue lias, are less liable to be injured by the same mode of proceeding, yet after my attention was drawn to this subject, I ascertained, that one out of three artificial stones made with chalk lime and water, split in the course of 24 hours, and two out of three artificial stones, made of 1 measure of Halling lime and 3 measures of sand, cracked in several places four days after they were moulded, though all made of lime that was supposed to have been thoroughly slaked. In fact, the number of artificial stones experimented upon by us in 1837, was less by about one-third than the number actually made the year before; and as we did not always record the circumstances that caused the defective ones to be thrown away, excepting such as failed from too early immersion, which was so remarkable a fact that it could not fail to draw

pointed attention; and as we did not at that time suspect that the common mode of making artificial stone in this country was objectionable, I can only now state as a matter of opinion, that in all probability a considerable proportion of them must have gone to pieces, from the cause now under consideration. The circumstance of even chalk lime being liable to injury from the tardy slaking of refractory particles, is so well known to the plasterers, whose inside work is often cracked from this cause, that although this is the quickest slaking lime known, they always drown their lime by *running it*, as it is technically termed, with great excess of water, and leave it a long time before they use it, in order to obtain it perfectly stale, and thus to guard against this unfavourable contingency.

THAT QUICK-LIME POWDER SHOULD NEVER BE USED IN MAKING ARTIFICIAL STONES, BUT THAT IT IS LESS OBJECTIONABLE IN MAKING CONCRETE FOR FOUNDATIONS, &c.

(209) Though, for the reasons that have been stated, I consider the usual mode of forming concrete with quick-lime powder to be inferior to the system of working with lime thoroughly slaked, as adopted in the construction of the sea wall at Brighton, yet as applied to the foundations of buildings, or to the backing of wharf walls, the use of quick-lime powder, fresh from the kiln, does not appear to be by any means objectionable; for in such very large masses, if a temporary weakness should take place in any part of the concrete, from partial slaking, it may be remedied by the weight of the superincumbent mass afterwards added in a moist state, which will cause the whole to consolidate; whereas in building dwelling-houses, as Mr. Ranger has done, with single artificial stones of the same substance, which set at the surface before they are used, a defect in any one stone, arising from the same cause, cannot be remedied in this manner. If it should be split in two, which I have sometimes observed to be the case, this stone must either be entirely rejected, or the fracture patched with mortar in an unsatisfactory manner.

(210) The impropriety of using lime in the same manner as cement was further proved, when we attempted afterwards to unite some stone bricks by means of blue lias lime in its net state, mixed with water alone, with a view to ascertain the comparative adhesiveness of this lime. By way of experiment, in our three first trials we reduced the blue lias

lime, fresh from the kiln, to the state of quick-lime powder, by pounding it in a mortar; and then, making it up into a stiffish paste, we applied it immediately to the proper surfaces of both stones, which we cemented together, and pointed the joint all round, in the same manner precisely, as we had done in all our cement experiments; so that the union of the two surfaces was completely effected, before the lime paste had thrown out any perceptible warmth. In the course of less than an hour, the blue lias lime heated, and swelled in all directions whilst slaking, so that the edges of the lime joint projected perceptibly beyond the sides and ends of the stone, with which they had originally coincided, which alteration of form, combined with its upward expansion in the direction of least resistance, caused it to crack horizontally throughout nearly its whole upper surface, and to detach itself from the upper stone entirely or nearly so; at the same time that it also separated, but more partially, from the lower stone. On removing the upper stone, the furrows and holes cut in the roughish surface of it by the masons, left their impression on the lime in relief, in as perfect a manner as could have been obtained by means of a plaster cast: and on separating the lime from the lower stone also, which it quitted with little difficulty and without breaking, the same appearance was exhibited on the under side of the thin cake of hydrate of lime, which had for a short period been the common joint connecting these two stones. This specimen, on being preserved, became exceedingly hard, and appeared to set into as firm a substance nearly as the joints of similar experiments, in which net cement had been used. And I have no doubt but that the blue lias lime would unite stones together, nearly as powerfully as the best cements are capable of doing, if it did not swell in all directions, when the attempt is made to combine the two processes of slaking and setting, which take place simultaneously in cements, without increase of bulk, and consequently without forcing them to split or to detach themselves from stones or bricks.

(211) Upon the whole, I was therefore induced to attach little value to the results of the experiments recorded in Tables VI. and VII.; but whilst I regretted that our investigation of the comparative resistance of artificial stones or concretes, as attempted in those experiments, should have been so unsatisfactory, yet, considering that it would require at least six months from that period to try them again in a more accurate manner, I determined not to postpone the in-

tended publication of my Treatise on that account, as my chief object in first undertaking it, was rather to ascertain the properties of calcareous cements, than of calcareous mortars or concretes, although they are too intimately connected to allow either to be discussed, without some reference to the other.

(212) As the value and importance of artificial stone used for the walls of buildings, or for those of wharfs or docks, must in a great measure depend upon its strength in opposition to a breaking weight, it now appeared desirable to ascertain its resistance in competition with that of the common building stones of this country, as well as with that of bricks and of sound chalk from the quarry, for which purpose I caused a number of similar small prisms, each 4 inches long and 2 inches square, to be cut out of all those substances, which being subjected to the proper breaking apparatus, yielded the results contained in the following Table, No. VIII.; and in order to render this more complete, the cohesiveness of the same stones in opposition to weights tending to tear them asunder has been repeated from Table III., whilst that of well burned bricks and that of inferior bricks have been estimated, from the average of the strongest and of the weakest results, recorded in Tables I. and II.

TABLE VIII. COMPARATIVE RESISTANCE OF VARIOUS NATURAL STONES, BRICKS, AND CHALK, REDUCED TO SQUARE PRISMS OF THE SAME DIMENSIONS AS THE SMALL ARTIFICIAL STONES BEFORE EXPERIMENTED UPON, WITH THEIR COMPARATIVE COHESIVENESS ALSO.

Description of Stones, &c.	Weight of Prism, in Troy Grains.	Weight per cubic foot, in lbs.	Breaking weight, in lbs., in several successive Experiments.			Average resistance, in lbs.	Average cohesiveness, in lbs.
1. Kentish Rag. . . .	10739	165·69	4286	3817	5099	4581	3773
2. Yorkshire Landing	9571	147·67	2976	2500	3185	2887	3642
3. Cornish Granite . .	11164	172·24	3179	2801	2445	2808	3841
4. Portland.	9598	148·08	2195	2892	2958	2682	4004
5. Craig Leith	9383	144·77	1940	1786	1961	1896	2439
6. Bath	7945	122·58	708	694	596	666	1408
7. Well burned Bricks	5944	91·71	704 955 722	795 622 706	717 640 823	752	3007
8. Inferior Bricks . .	. . . .	. . . .	204	262	522	329	1105
9. Pure Chalk (dry) .	6157	94·99	414	265	314	334	473

(213) From the above experiments it appears, first, *that the* RESISTANCE *of various stones in opposition to a breaking force, is not in proportion to their specific gravity, nor in any*

direct proportion to their COHESIVENESS *in opposition to a tearing force.*

Secondly. An examination of the results recorded in this last Table, compared with those of Tables VI. and VII., will perhaps convince the reader as it has done me, *that artificial stone made according to Mr. Ranger's system is very much inferior, not only to all the natural building stones in common use in this country, but even to sound well burned bricks.* For in the walls of buildings, which are exposed to weather, and may be subject to external violence, that sort of resistance in which this substance seems to be deficient is one of the most important qualities, though not in foundations and backing, which are exposed to dead weight only.* In fact, those experiments prove that artificial stone, after allowing a year for the lime to set, is inferior in strength even to common chalk in its dry state, which has been rejected for many centuries as being unfit for the purposes of building.† Supposing my objections to the usual method of forming artificial stone with quick-lime powder, as developed in Articles 204, 205, and 207, to be well founded, it follows that a stronger artificial stone may be formed by working with thoroughly slaked lime. But admitting this much, it must also be allowed that no conglomerate substance composed of very small ingredients can be stronger than its weakest part; and therefore the resistance of an artificial stone is not to be measured by that of the flinty pebbles or gravel which are its strongest part, but by that of the comparatively weak lime or mortar, by which those pebbles are connected together, and which I believe can never rival the hardness of any sort of stone, except in a very thin coating or skin just at the surface. Upon the whole, therefore, I would recommend that even Bath stone, the weakest building stone in

---

* This opinion, formed in 1837, has been so far modified by the subsequent experience of eight years, that I fully admit the probable durability of the walls of houses built with Ranger's artificial stone, with the exception of cornices, or other projecting ornamental mouldings, which it will be necessary to repair from time to time, as is now being done (October 1845) at the College of Surgeons, Lincoln's Inn Fields, the outer surface of those mouldings being nothing more than stucco, of a quality depending on the sort of lime used; and with the exception also of the lower parts of the walls of artificial stone houses within reach of persons passing, which are much more liable than brick or stone to be injured by accident or from mischief, or even from curiosity, because, though these walls have the appearance of stone, they generally show here and there dark nodules of pebbles protruding through the light coloured coating of stucco, which may tempt persons observing them to explore deeper than the surface.

† Chalk was used probably before the Norman Conquest, for the filling in of thick walls, and also occasionally for inside vaulting, of which specimens may be seen at Canterbury and Rochester. It is still used in some parts of Norfolk for the walls of cottages, or for inclosures, but not for any buildings of importance.

England, or where stone is not to be had, that good brickwork, stuccod with cement, should be used in preference to artificial stone, not only for public edifices, but even for the mansions of opulent private individuals.* At the same time I shall repeat my former observation, that *I consider concrete, if kept within proper bounds, to be a most excellent and useful expedient.* Rejecting it therefore entirely for the facing of piers or wharfs, exposed to the constant action of the tides, or of wet docks and basins, and generally, though not absolutely, for the walls of buildings, and for arches or vaults, it should be confined chiefly to foundations, in addition to which it may also be used for the backing of wharf walls, or other retaining walls, and even for the formation of retaining walls, such as that of the East Cliff, at Brighton, provided that they are not exposed to water in mass. It may also, as I said before, be used for military revetments in peculiar situations, as for example, in fortifying sandy islands (32).

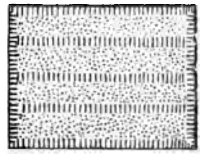
EXPERIMENTS TO ASCERTAIN WHETHER CEMENT MAY BE USED TO ADVANTAGE IN MASONRY, ESPECIALLY THAT COMPOSED OF VERY LARGE STONES.

(214) The circumstance of cement having hitherto been used almost exclusively for brickwork, in and near the Metropolis, has produced an impression on the minds of many practical men, that it is not applicable to stone walls, especially if to be built of very large heavy stones, for two reasons; first, from a supposition that it does not attach itself well to stones, and secondly, because it sets too quickly to admit of a very large heavy stone being properly adjusted, without disturbing the bed of cement upon which it is to be laid. The first supposition has been proved to be erroneous, by the experiments recorded and commented upon in the preceding articles. The second, which I considered no less unfounded, induced me to try the following experiments.

Having provided two large Bramley-fall stones of the same size and weight nearly, I caused the top of one and the bottom of the other to be dressed in the same manner, as would be proper for the common joint of the stones of two successive courses of large ashlar masonry, suitable for the wharf wall of an important pier or harbour, or for the wall of a lighthouse exposed to the action of the sea. This was done by cutting them all round by a mallet and a bosting tool or chisel 1½ inch broad, and afterwards cutting three intermediate spaces, parallel to and equidistant from the long sides, and by then picking down the remaining rectangular portions of the surface by a pointed tool, as shown in the annexed figure, in which the small furrows cut by the chisel are represented by short parallel lines, whilst the pick holes are dotted, neither of them penetrating more than one-eighth of an inch below the general surface of the two stones, each of which, after being thus dressed, measured nearly 39 inches long, 29 inches broad, and 26 inches deep, and weighed about 2662 lbs.

---

* I do not consider that the resistance of the concrete casemate at Woolwich to the fire of heavy artillery, as recorded in Article 32 and the note to 33, invalidates this opinion, because we found by our experiments at Chatham, that the penetration of a 24-pound shot into a parapet of loose fine sandy soil was only double its penetration into the wall of that casemate. In the absence of positive experiments, I conceive that the resistance of the weakest sort of stone now used for the purpose of building, would exceed that of loose sand in much more than a twofold ratio.



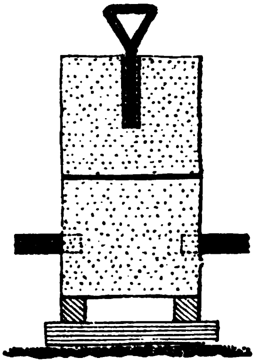
That stone which was to represent the lower course of masonry in our proposed experiment had four iron bearers, each 14 inches long and three-quarters of an inch thick, let into it, 4 inches deep, so as to project 10 inches from opposite sides, and towards the ends of the stone, in a horizontal direction. These bearers were fixed with the same artificial cement about to be experimented upon. The upper stone had an eyebolt sunk into it to the depth of 16 inches, for raising it when necessary, which was of a dovetailed form at bottom, and wedged into a hole cut in the stone, of much greater diameter than the shank of the bolt, by small fragments of granite.*

After being thus prepared, the first stone was set upon strong wooden skids, to represent, as before said, one stone of a finished course of masonry, and the other being raised by hooking on the eyebolt to the tackle of an artillery gyn, was let down upon the former in such a manner, that the two surfaces which were to be afterwards cemented together were made to coincide properly, which, being of equal size, and both out of winding, they could not fail to do.

---

* This eyebolt was made of 1¼-inch bolt iron, and let into a hole 3 inches in diameter cut in the stone. At the distance of 4 inches from the lower end of the bolt, its thickness was made to increase from thence downwards, in a conical form, till it became about 3 inches in diameter, and thus nearly fitted the bottom of the hole. After inserting the eyebolt into its proper place, small pieces of broken hard stone were poured in, which filled the cavity round the upper part of the hole, and became jammed there as soon as a purchase was applied. This simple arrangement, suggested by Mr. Howe, prevented the bolt from being drawn out of the upper stone, when afterwards acted upon by a total weight exceeding 39,000 lbs. avoirdupois. He had previously recommended it to Captain Chesney, as a good mode of fixing moorings or warping-eyebolts in rock, for the proposed navigation of the Euphrates, which was afterwards undertaken by that Officer, with the local rank of Colonel in the East.

Having thus adjusted the stones in a dry state, we raised the upper one again to the height of about 1 foot by the gyn, after which the cement, which consisted of mixture C 4 B 5, was made up with water into a stiffish paste, and thrown upon the top of the lower stone, upon which one bricklayer spread it properly, whilst another applied the superfluous parts of it in a thin coat to the bottom of the upper stone, in the same manner as would be done in plastering a ceiling, both working with long-handled tools resembling large garden spuds or small spades, instead of the trowel, which could not be used conveniently in the confined space between the two stones. After the surfaces of both were thinly coated with cement, they were united by letting the upper stone gently down into its proper place upon the lower one, where by its great weight, which exceeded a ton, it pressed down the bed of cement, which was still soft, to a regular thickness, squeezing out a part of it on each side out of the joint, which was pointed all round by the bricklayers with their trowels.



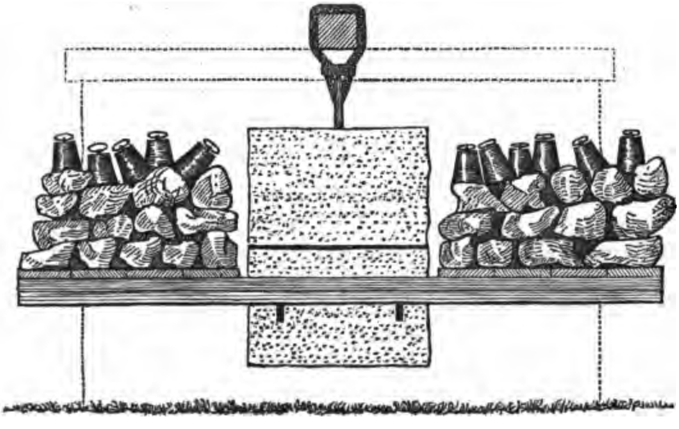
The gyn was then removed, and the stones thus cemented together were allowed to remain upon the skids, in the state represented in section in the annexed figure, which shows two of the four iron bearers that were cemented into the lower, as well as the iron ringbolt that was sunk into the upper stone.

At the end of ten days, the gyn was again erected, and the upper stone hooked on to it, and raised about an inch, on which the cement joint gave way, being torn asunder by the lower stone alone, which, with the iron bearers attached to it, weighed about 2688 lbs. This first experiment was by no means promising, but as the stones had been cemented together during a frost, it seemed possible that the weather might have affected them. If not, 10 days was evidently too short a period to enable the cement joint to bear the weight of the lower stone. We therefore determined to try the same experiment again, but allowing more time for the cement to set.

(215) Accordingly, having cleaned the proper surface of each

stone, we cemented them together again, and at the end of 60 days we raised them up by the gyn, and having laid two strong deals longitudinally upon the iron bearers on each side, and short sheeting or mining planks transversely over the ends of these, so as to form a sort of double platform resting upon the lower stone, we laid successive weights upon these deals and planks, until the mass broke down and fell to the ground, through a distance of about 1 foot, for at this period we had removed the skids. The total weight applied was 7083 lbs.; but on examination it proved to be the hook of the artillery gyn that had snapped in two, which must have been of bad, probably remanufactured, iron,* whilst the cement joint of the stones, notwithstanding the concussion of the fall, was to all appearance still perfect;† but further experiments afterwards led us to believe that this opinion was erroneous; for if C 4 B 5, the artificial cement now used, had not been seriously injured by the fall, it ought to have proved, as in all other trials, nearly equal to the best of the natural English cements; whereas it did not, after this accident, evince more than one-fourth of the adhesiveness of Messrs. Francis's English cement, when applied to the same two stones, as will presently be related.

(216) In continuation of our experiments with the large



---

* Remanufactured iron, which from my experience I consider to have been of very inferior quality, was used for some years in the Ordnance Department, probably from its cheapness; but as nothing that is bad is really cheap, it has since been disused by order of the Board.

† This experiment was tried in presence of Sir James R. Carnac, Chairman, and several Directors of the Honourable East India Company, on the 30th of March, 1837, after they had inspected their Dépôt under the command of Lieutenant-Colonel Hay, for which purpose they had visited the Garrison of Chatham.

Bramley-fall stones, eight days after the accident that has been mentioned, we again raised the stones by the same gyn, which we had fitted up with a new hook, but before we applied any weights to the lower stone, we suspended the mass to a strong beam of wood, properly supported in a temporary manner by two piers made of the woodwork belonging to our pontoon equipage, and then removed the gyn, as we were apprehensive that some other part of it might break down and spoil our experiment. We then laid on the longitudinal deals and transverse planks as before, and loaded this sort of framework with paving stones, each weighing from 30 to about 70 ℔s., and over them iron 56 ℔. weights. The foregoing figure represents this arrangement, in which the beam that bore the whole weight, and the transverse planks, are represented in section, the other parts being distinctly shown in elevation, except the temporary wooden piers which supported the beam, of one of which the outline only is marked by dotted lines.

Thus we proceeded as before, continually adding more weights, until the mass broke down under a weight of 9660 ℔s., the details being as follows.

Weight of the lower Bramley-fall stone . .	2630 ℔s.
Four iron bearers	32
Four 3-inch deals laid longitudinally . . .	311
Eight planks laid transversely	224
Sixty-nine pieces of paving stone	3637
Fifty iron half-hundred weights	2800
Total weight that broke down the mass . .	9634 *

Usual appearance of cement joints after being fractured. On examining the cement joint, which was the part that had now given way, it did not average more than one-tenth, and nowhere exceeded one-eighth of an inch in thickness, excepting where it entered into the chisel furrows or pick holes; and the greater part of it adhered to the upper stone, leaving the roughish surface of the lower stone generally as clean, to all appearance, as if no cement at all had been applied to it; and we had observed the same circumstance in our experiments with bricks and stone bricks, in which also, whenever a cement joint gave way, one of the two surfaces connected by it appeared nearly clean. Hence, if the great weights required to effect separation in most of our experiments had not sufficiently proved the excellence of the cement joints, we might have supposed them all to be imperfect; but considered in another point of view, this proves that the cohesiveness of a cement joint, in opposition to a force tending to tear the cement itself asunder, is greater than its adhesiveness to stones or bricks, although the latter is so powerful, that in the demolition of brickwork built not only with net cement, but even with cement mortar, the bricks themselves are more often fractured than the joints.

---

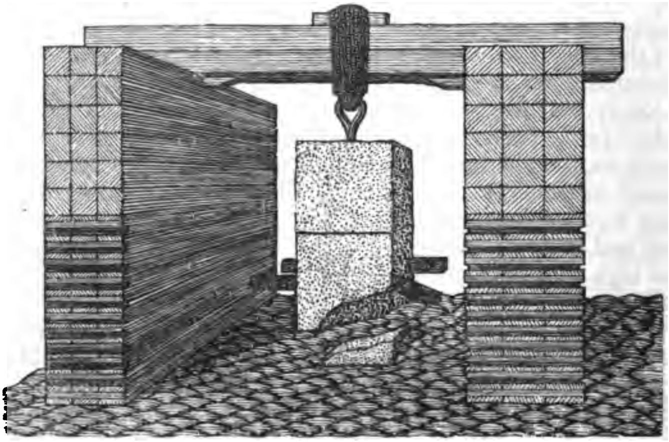
* This experiment was tried in presence of Lieutenant-Colonel Hay and Major Somerville, of the East India Company's Dépôt, Captains Jebb and Mackenzie, of the Royal Engineers, and other Officers both of the King's and Company's Engineers. Mr. Howe was also present, and directed the workmen in this, as in all the other experiments.

(217) Having occasion to purchase several casks of cement of Messrs. Francis and Sons, for an experiment of a different nature, that will afterwards be recorded, I caused the same two Bramley-fall stones to be cleaned and cemented together in the same manner by some of this cement, which was composed of a mixture of Sheppy and Harwich cement stone, but in what proportions the manufacturers did not inform me, which, according to the custom of the trade, though in reality *English cement*, was falsified by the absurd title of *Roman cement*. On trying to break down the cement joint when six weeks old by the same process before explained, one of the 3-inch deals broke, and a crash took place after more than 19,000 lbs. avoirdupois had been applied, but the cement joint was uninjured, as part of the weights only had fallen to the ground. Three days afterwards, having suspended the stones by two fir beams instead of one, which we deemed unequal to support the probable weight, and having laid a couple of oak beams, 14 feet long and 9 inches square, upon the iron bearers, instead of the 3-inch deals, and having laid double rows of short planks transversely across the ends of the beams to support the necessary weights, we attempted to break down the same cement joint a second time, having previously borrowed a quantity of pig iron ballast from Chatham Dockyard, which we thought, in addition to our former weights, would be quite sufficient to effect this object: instead of which, to our extreme surprise, after exhausting all our iron weights and ballast, and a number of paving stones, we laid on sand-bags filled with earth until they were heaped so high that no more could be added without oversetting the pile, and therefore we left off for the night without removing any of the weights, with an intention of borrowing more iron ballast from the dockyard next morning. But probably, in consequence of the rain which fell during the night having increased the weight of the sand-bags, a fall accompanied by

a loud crash took place about one o'clock in the morning; but on examining the apparatus, and clearing away the confused masses of fallen weights after daylight, the cement joint was found to be still perfect, instead of which the lower stone itself had given way, a fragment of which weighing 203 lbs. of an irregular triangular form had broken off, immediately under one of the four iron bearers, which was bent downwards, but not broken. As soon as this gave way, one of the oak beams, being deprived of its support at one end, snapped in two, and the other beam also broke in consequence. The detail of the parts of the load that had been used, which were carefully weighed next morning whilst the sand-bags were still damp, was as follows:

Lower stone, and its iron bearers	2,662 lbs.
Two oak beams	679
Twenty-two 2-inch sheeting planks . . .	611
Sixty iron 56 lb. weights	3,360
Pig iron ballast of different sorts	15,242
Paving stones of Guernsey granite . . .	3,097
159 bushel sand-bags filled with earth . .	10,893
Total lbs.	36,544

The annexed figure represents in perspective the two stones that had been experimented upon, after the weights that had broken off a part of the lower one were removed. As there was now no possibility of separating the cement joint by weights, in consequence of the mutilated state of the lower stone, we split it by means of chisels and



mallets, and were not a little surprised to find, that with the exception of the outer part of the cement that had been exposed to the air, which was extremely hard, the whole inside of the cement joint was softish, and neither resisted the action of the thumb nail, nor of a sixpenny piece on edge, which being drawn along the surface, scored it to the depth of nearly a sixteenth of an inch. The two fir beams, having a piece of teak over them in contact with the rope by which the stone and load were suspended, had undergone a deflection of 1 inch in 6 feet 8 inches of bearing, and the oak beams had undergone the same nearly, but in a contrary direction, being supported near the middle and not at the ends; but the 2-inch tarred rope, which was used in 23 folds, was not injured, and not the least extraordinary part of this remarkable experiment was the resistance of the small pieces of broken granite, by which the eyebolt, bearing the whole weight of more than 39,000 lbs., was jammed in the upper stone. The strength of the iron bearers, each subject to a weight of more than 9000 lbs., was also worthy of notice, being a proof of the efficiency of iron cantilevers set in stonework by cement, for the purpose of supporting balconies, &c.*

(218) The experiments thus tried with the large Bramley-fall stones having only proved that a large cement joint of good natural English cement, 45 days old, is at least as strong as that excellent sort of stone, if not more so, though, owing to the failure of the hook of our suspending apparatus, they did not afford us any criterion for judging of the comparative strength of our artificial cement, I next determined to try the strength of two similar cement joints only 11 days old, in competition with each other, one of Francis's best cement, such as had been used in the last experiment, the other of C 4 B 5·5; for which purpose we prepared four Bramley-fall stones, each measuring 1000 superficial inches on the corresponding surfaces, which were to be cemented together, and each averaging from 11½ to 12 inches in thickness, so that they did not weigh quite half as much as the first large stones, out of which in fact three of them were made, by splitting the former at the middle of their original

---

* This experiment was tried on the 9th of June, 1837, in the presence of numerous spectators, who were perfectly astonished at the extraordinary strength of the cement joint. Besides all the Officers of Engineers, Colonel Warre, the Commandant of the Garrison of Chatham, and a great number of Officers of various Regiments attended, as well as Captain Clavell, Superintendant of Chatham Dockyard, together with several members of the Philosophical and Literary Institution, and other Gentlemen, Tradesmen, and Mechanics.

thickness. This experiment, which we hoped would have been definitive, unfortunately led to no satisfactory result, in consequence of the eyebolts, which were now fixed only 9 inches into each stone, drawing out of the holes before the cement joints were injured. Hence, the two stones united by Francis's cement fell down, together with the platform and weights applied to the lower stone, when the weight acting upon the joint amounted to 4193 ℔s., and after falling from the height of about 1 foot upon a couple of wooden skids, the cement joint proved to be broken by the fall. The weight bearing upon the joint of the artificial cement C 4 B 5·5 amounted to 5975 ℔s., after which the eyebolt was also drawn out of the hole, and the two other stones, with their load, fell through the same space down upon a stone pavement, but the cement joint was to all appearance perfectly uninjured, and we could not separate the two stones without splitting the joints by several smart blows of a mallet and chisel. On examining the two joints, Francis's cement was thinner, being only from $\frac{1}{10}$th to $\frac{1}{8}$th of an inch, and what is termed much shorter or more brittle than the artificial cement joint, which averaged from $\frac{1}{8}$th to $\frac{3}{16}$ths of an inch in thickness, and was much tougher than the former. The thumb nail or edge of a sixpenny piece acted on both of them. All the spectators agreed in opinion, after the untoward end of this experiment, that if the mode of fixing the eyebolts had not failed, the artificial cement would have gained the victory in this competition, which they inferred not only from its having sustained the shock of the fall without injury, but from its more perfect state, especially in the centre of the joint.* The result of this experiment also proved, that the artificial cement joint 10 days old, which was first tried with the Bramley-fall stones, must have been spoiled by the frost as we suspected (214), and that the second more perfect artificial cement joint 60 days old must undoubtedly have been injured by its previous fall (215); otherwise there seems every reason to believe that no weight much less than 30,000 or 40,000 ℔s. could have broken it down at that age.

(219) Two out of the four stones thus experimented upon having been broken, we connected the other two by a joint of our artificial cement mixture C 4 B 5·5, and used the

---

* This experiment was tried on the 15th of July, 1837, in presence of the Officers of Engineers as usual, and also of Colonels Tremenheere and Lawrence, of the Royal Marines, besides Mr. Howe, and other Clerks of Works employed under Government, and some Officers of the Dockyard.

common mason's lewis for suspending them, which was done by letting it about 5½ inches into the uppermost stone. On applying weights in the usual manner when the cement was 11 days old, the joint was torn asunder by 8459 lbs., but on inspection it was found to be imperfect, part of the space between the two stones being without any cement for about one-sixth part of the whole extent, so that from this defect in the centre of it, the real surface of cement joint acted upon was only about 830 superficial inches, instead of 1000, which it ought to have been.

At the time when this fracture took place, the lewis was gradually being drawn out of the upper stone, which had been splintered in consequence, and would certainly have given way before the joint, had the latter been perfect.

We therefore repeated the same experiment after cleaning the stones, taking every pains to make our new cement joint of 1000 superficial inches quite perfect, and now, instead of a lewis, we used an iron plug, secured into nearly the whole depth of the upper stone by melted lead, and so formed that it could not possibly be drawn out without breaking the stone.

After applying 7110 lbs., the bolt of the shackle of this iron plug broke, and both stones, with the weights bearing on the lower one, fell to the ground.

Having replaced the iron bolt by a piece of steel of greater strength, and submitted the same joint, which appeared uninjured, to a second trial, the plug itself broke off close to the upper stone, after 11,825 lbs. were applied, and the stones and weights again fell to the ground.

Next day, as the joint, which was now 17 days old, still appeared uninjured, we cut mortises into opposite sides of the upper stone, each 5 inches deep, in which we inserted iron bearers, and secured them with melted lead; and having again suspended our two stones by these bearers, we applied weights to the lower stone as before, and gradually increased them until the joint was torn asunder, which was effected by a total weight of 12,982 lbs. The cement in this joint happened to be unusually thick, being $\frac{7}{16}$ths of an inch in mean thickness, so that some parts of it were more than half an inch thick, which seems to prove that thick joints are not so very prejudicial to the strength of brickwork or masonry laid in cement, as we had before supposed.

Considering that the joint might have been shaken by the two falls, as well as by the act of cutting the mortises that have been mentioned into the upper stone, the great weight required to tear it asunder, after those circumstances, is a proof that our artificial cement possesses not only great adhesiveness but considerable toughness or cohesiveness, in which last and very important quality, we had before remarked that it appeared to excel the natural cement.

Upon the whole, the above experiments, tried with Bramley-fall stones connected by large joints of cement, so far disappointed us, that they did not afford us the means of judging of the comparative strength of the best of our artificial cement mixtures and of the excellent natural cement, used in competition with each other, in consequence of various parts of our apparatus repeatedly failing, which we considered so strong that we had no expectation of their giving way sooner than the cement. These experiments, which occupied more than seven months, from the setting of the first cement joint to the last trial inclusive, have been related consecutively, in order not to interrupt the thread of our narrative, though other experimental proceedings, of prior date to some of them, took place in the mean time. Unsatisfactory in one point, as has been observed, their results, combined with those of our previous experiments with stone bricks, recorded in Table V. (195), and remarked upon in the two succeeding Articles (196 and 197), have fully established the following important principle, viz.:

THAT CEMENT MAY BE USED TO THE GREATEST ADVANTAGE, FOR MASONRY, EVEN OF THE LARGEST STONES.

(220) In building masonry of small stones, whether of ashlar or rubble work, with cement mortar, it will be evident that the only precaution necessary will be to take care not to use stale cement, and not to disturb the cement or cement mortar when set; in short, to follow the same well known rules always observed in laying brickwork in cement. In working with very large and heavy stones, in which a crane or other machine for lifting them must be used, the only additional precaution necessary is to adjust each stone of every new course, to the stone or stones of the course below upon which it is to be laid, first in a dry state, and then to raise it again before the bed of cement for the joint is applied, which must be done in the same manner in which we put together our Bramley-fall stones, as before explained (214). As the strongest cement, whether natural or artificial, does not set in less than from 15 to 20 minutes, or sometimes more, and as it cannot require more than 5 minutes at the utmost to place the largest stone properly, after having once adjusted

it dry, it is impossible that any difficulty can occur in building masonry with cement, provided that this arrangement be adopted.*

THAT THE ADHESIVENESS OF CALCAREOUS CEMENTS SHOULD NOT BE ESTIMATED BY THE SUPERFICIAL INCH.

(221) As the surface of the joint of Francis's best English cement connecting our two largest Bramley-fall stones, measured 1131 superficial inches, which resisted 36,544 lbs., and then the stone gave way (216); what farther weight it might have borne had the stones continued perfect, must be a matter of conjecture; but from the softish state of the cement, which in all our former experiments on a smaller scale we had observed to be a proof of weakness, I do not think that it could possibly have resisted more than about 56,000 lbs. at the utmost, which averages only 50 lbs. to the superficial inch, whereas one of our artificial cement joints, 74 days old, applied to bricks, and measuring about 40 superficial inches, resisted more than 4400 lbs., after which the bricks gave way, thus evincing an actual adhesiveness of 110 lbs. to the superficial inch, which, if the bricks had been stronger, may reasonably be estimated at 125 lbs. to the inch, as was before implied (181). Though somewhat of this opinion is conjectural, still I consider it to be a safe and accurate conclusion, that any cement, whether natural or artificial, as applied to a very large joint, such as that of the two Bramley-fall stones, may be torn asunder by a much smaller weight in proportion to its surface, than that which would be necessary for separating the joint of two much smaller stones, connected by cement of the same quality and age. But the strength of the same cement used at the same age, and under the same circumstances, must necessarily be equal; so that the apparent difference in the adhesiveness of cement applied to a very large joint, and to a much smaller one, only confirms what I have before so often stated, that cement in large masses, not easily accessible to air, sets very slowly; for this was the case with our large joint, the whole of which, except just round the edges, being

---

* If the system customary in building large masonry with lime, that is, to lay the bed of mortar first and to get the stones into their places afterwards by a crane or other machine, were adopted in using cement, bad workmanship would necessarily be produced. Even in building with bricks, which are laid so much more quickly than stones, if the same mode of using cement mortar were adopted, that is usual and proper in building with common mortar, the work would be ruined. In short, one sort of manipulation is necessary in using cement, whilst another is better in working with lime, and if properly understood, the former is as easy as the latter.

inaccessible to the external air, it was therefore in the same predicament as the central parts of a large mass of cement. Hence the system adopted by some authors, of estimating the adhesive strength of calcareous cements, in some proportion to the superficial inch, is only true when all the joints are equal and similar surfaces, and equally accessible to the external air, or to water if used in hydraulic works; and as this can never be the case in practice, it is best not to estimate the comparative adhesive strength of cements by the superficial inch at all, which is very likely to lead to error. In fact, the adhesive strength of any joint made of the same cement, is directly as the age of the cement, and inversely as the magnitude of the joint; but it is not equal or proportional throughout the whole of very large joints, the outside of which may be at the rate of 125 ℔s., whilst I conceive that their inside may not exceed 30 or 40 ℔s. to the superficial inch, as measured by the weights capable of tearing them asunder. But as there must, after a certain period, be a maximum both of ADHESIVENESS in opposition to forces tending to tear cement away from the stones or bricks united by it, and of RESISTANCE, or absolute strength as opposed to a breaking or crushing weight, which no cement can exceed; and as both stones and cement are porous, and not absolutely impenetrable either to air or water, I have no doubt, but that in process of time, the central parts of large masonry built with cement, will attain the same perfection as the outside, though much more slowly.

(222) I was partly induced to try the above experiments with those Bramley-fall stones, by reading the account of the construction of the Edystone Lighthouse by Smeaton, and of the Bell Rock Lighthouse by Mr. Stevenson, of Edinburgh, both of which reflect the highest credit upon those distinguished Civil Engineers, especially the former, whose proceedings the latter adopted as his text book, although many of his own arrangements were perfectly original, and his task, upon the whole, was by no means less arduous. In considering this subject, I am ready to admit that nothing can be better than these celebrated lighthouses, as they now stand; but as the powerful water cements of England, absurdly termed Roman cements, were absolutely unknown in Smeaton's time, and the use of them may be said to have been in its infancy when the Bell Rock Lighthouse was built, and even now is by no means general in Scotland; a query occurred to my mind, whether in the event of the erection of some future lighthouse in such exposed situations,

a great part of the difficulties encountered, which arose chiefly from the enormous weight of the stones, might not be avoided, by using large heavy blocks of granite for the outside courses only, and by building the whole inside of the lower or solid part with bricks, or with hard stone if that be preferred, in light and manageable pieces, not requiring the aid of machinery to move them, and all laid in cement. For this internal part of the bottom of a lighthouse, flat bedded stones, capable of being split to any thickness, and having consequently very regular horizontal joints requiring little cement to make them good, such as were recommended by Smeaton for the backing of walls exposed to the action of water, would be extremely applicable.* The vertical courses of large masonry built with cement might be filled in with cement grout, in a state not more fluid than just to allow it to run freely into every crevice. In respect to Smeaton's stone joggles, they may be used if necesary, but his oak trenails must be dispensed with as a matter of necessity, because driving them might disturb the cement in the act of setting. And it appears to me that his dovetails in the stones may also be dispensed with, which will save a great deal of expense in cutting and of trouble in placing them; for if all the large outside stones of each course be cut, so as to form a horizontal circular arch, inclosing a solid central mass of smaller materials, and the whole laid in net cement, the adhesiveness of which, considerable even from the first, will in time equal or exceed the cohesiveness of the stone itself, I see no risk of the heaviest sea being able to displace any of them. In adopting this arrangement, the outside stones of successive courses should be all headers and all stretchers alternately, so as to break bond with each other, but there is no objection to their being all of equal length nearly, in the same course.

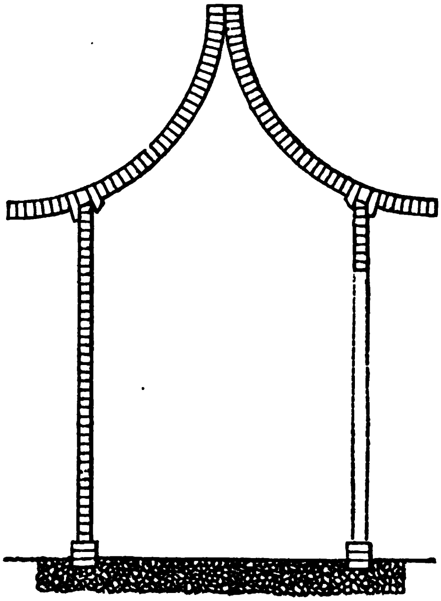
In like manner, the arches of first-rate bridges also might undoubtedly be built with bricks, or with long thin stones of moderate weight, at least in situations not near to the Metropolis or other great cities, and not on the line of much frequented public roads, where I should be sorry to oppose the expensive luxury of fine bridges, such as the Waterloo or new London Bridge, which, like other pieces of splendid architecture, are not always to be condemned, merely because plainer buildings would cost less money.

---

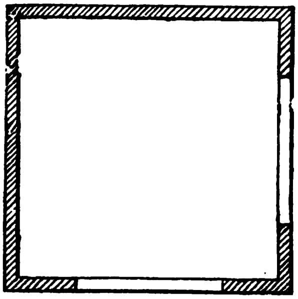
* The Whinstone of Scotland, recommended for Bridges by Messrs. Smith of Darrick, in an able paper in the first volume of the Transactions of the Institute of British Architects, would perhaps be no less applicable.

DESCRIPTION OF A REMARKABLE BRICK SUMMER-HOUSE, THE CONSTRUCTION OF WHICH WOULD HAVE BEEN IMPRACTICABLE WITHOUT CEMENT.

(223) The cement from Messrs. Francis and Sons, of which part was used in the foregoing experiments, had previously been procured for a small summer-house, which I was then desirous of building, in the garden attached to the Field Officer's quarter in Brompton Barracks, Chatham, occupied by me, and which, to answer also the purpose of an interesting



Section.



Ground Plan.

experiment in Practical Architecture, I determined to build entirely of brickwork and cement, making the walls and roof half brick thick throughout, and constructing the latter as a sort of hollow square pyramid with projecting eaves, and with curved sides, convex internally but concave externally. In short, the brickwork skeleton was purposely made by me of such a form, as could not possibly have held together, but for the cement.

This little building was 7 feet 2 inches square in the clear, and 9 feet 3 inches high from the foundation to the lower side of the eaves. It was built on a bed of concrete 1 foot thick, over which a brick foundation was laid, 9 inches thick and 9 inches high, and above this level the whole of the work was only half brick, or 4½ inches thick, as before mentioned. There were entrances left in two adjacent sides, each 4 feet wide and about 7½ feet high, which were covered by a horizontal line of bricks laid flat, with vertical joints, for I studiously avoided the arch-like form, excepting in the roof, where, by inverting that form, as was before stated, not strength but weakness ought to have been produced. The curved sides and the projecting eaves of the roof were formed by four equal quadrants, having their upper radii all in the same horizontal plane, and their convex extremities meeting at top, each radius being 5½ feet long.

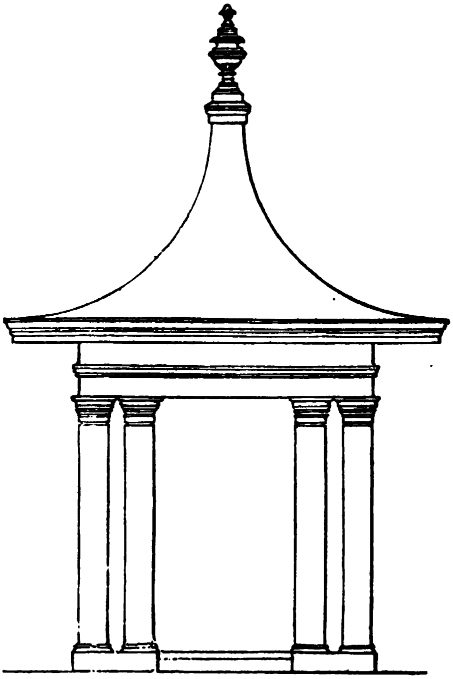
This construction is explained in the two foregoing figures, one of which is the plan of this little edifice. The other is a section of the rough brickwork, in which, notwithstanding the smallness of the scale, every brick is distinctly represented. As the eaves of the rough brickwork of the roof projected 2 feet each way beyond the walls, the roof, including those projections, measured 12 feet square at bottom.

This little building was stuccod inside, but on three sides only outside, the fourth exterior side, both of the walls and roof, showing the rough brickwork, in order that the construction may at any time hereafter be understood, by a spectator to whom it is explained; and as this rough side faces a boundary wall with a very narrow passage between, it is not seen from any of the walks in the garden. The following figure represents the appearance of one of the finished fronts of the building, having ornamental pilasters, and mouldings, and an urn on the summit of the roof.*

We used neither hoop iron, nor stone, in any part of the building. The projecting pilasters, &c., were roughed out by attaching fragments of plain tiles, or of bricks, to the surface of the original brickwork, by cement. The eaves were formed entirely of bricks stuck out by cement, in the same manner in which our experimental brick piers had been made to stand out from the face of a wall (175). The roof was built without centering, by a plumb line attached to a quadrantal level, and was carried all round by single courses at a time. The brickwork over each of the two entrances was built upon a piece of plank laid horizontally, supported at the ends by short upright pieces, which were pressed against the brick jambs, by an intermediate bar. Before the roof was commenced, four planks, composing a sort of square frame, were applied to brace the walls externally near the top, with iron tie-rods, to prevent them from separating, and with horizontal bars of wood inside, to prevent them from collapsing, the whole of which were removed as soon as the roof was finished. Net cement was used for all the rough brickwork, and also for the ornamental mouldings of the stucco, but not in the plain

---

* The decorations were designed by Mr. Howe.



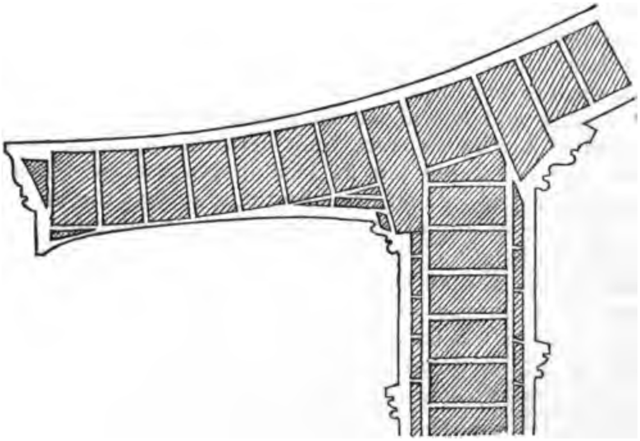
Elevation.

parts of the latter, which were done with cement and sand mixed in equal measures.

This experiment affords an additional proof of the wonderful adhesive power of cement; for any architect or builder, or even workmen of experience, will admit, that if lime mortar had been used instead of cement, the walls would have been very weak, and that the roof could not have been built at all without an interior framework or centering of wood, nor could the eaves have been added without some similar support; and after being finished by this apparatus, it will also be admitted, that the whole of this little fabric, supposed to be built with common mortar, would fall to pieces the moment that the centering was removed, even if the lime were previously allowed 20 years to set.

(224) In a former part of this Treatise I explained the usual modes of preparing for bold projections in cement fronts, by introducing Yorkshire stones, and by other expedients mentioned in from Article 126 to 128 inclusive; and afterwards, in reference to Mr. Brunel's celebrated experiment of the two semi-arches, springing from one central pier only (59), I remarked that there would be no difficulty in forming the boldest projections by brickwork and net cement alone, with the aid of hoop-iron in the joints, according to his system. The summer-house has since convinced me that the boldest brick projections necessary in ornamental architecture are practicable, not only with but without hoop-iron, and also that the expedient of nails and spun yarn to strengthen a cement moulding (128) is perfectly useless.

The annexed figure shows in section the details of the pro-



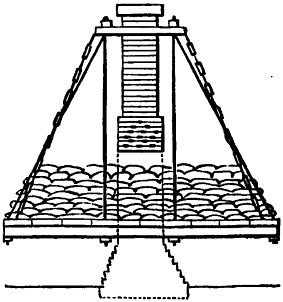
jections and mouldings at the meeting of the walls and roof of the summer-house, on a larger scale. Two bricks laid as headers, and cut to suit the forms of the mouldings, one brick between these laid on edge, and another brick below this, cut obliquely at the top of the wall, will be observed, which were the only courses of bricks in the whole work not laid flat and as half bricks. In this figure, the bricks and fragments of bricks are shaded dark, whilst the cement joints and stucco are light. The cornices were worked, or, as it is technically termed, *run*, by a mould, but some of the smaller mouldings were run separately at a board, and fixed afterwards.

REMARKABLE BRICK BEAMS BUILT WITH CEMENT AND STRENGTHENED BY HOOP-IRON BOND.

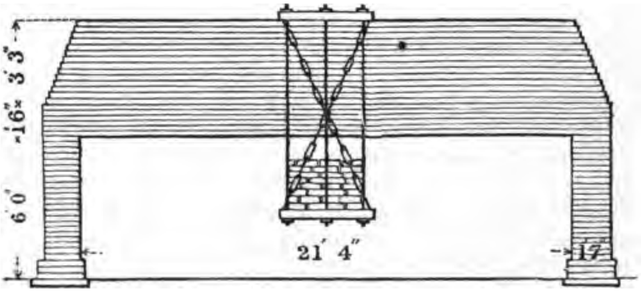
(225) Besides his extraordinary semi-arches (59), Mr. Brunel tried another experiment upon the strength of net cement, scarcely less remarkable, by building what he termed a brick beam, which was a substantial mass of brickwork, resting near its extremities upon two square blocks of wood, at the clear distance of 23 feet 9 inches apart, and having twelve pieces of hoop-iron, 1¾ inch wide and $\frac{1}{16}$ inch thick, introduced longitudinally, and distributed amongst five of the lower joints. The beam was 3½ bricks thick at bottom for the first three courses, then 3 bricks thick for one course, 2½ bricks thick for three courses more, above which the remainder of the work was 2 bricks thick, there being seventeen courses of brickwork in all; so that it measured about 4 feet 3 inches high. Two pilasters, as they may be termed, about 14 inches wide, and 5 feet apart in the clear, were carried up on both sides, increasing the thickness of the upper part of the beam from 2 to 3½ bricks at those points. The hoop-irons were distributed—three above each of the first, second, and third courses of the brickwork, two above the fourth, and one above the fifth course. The first seven courses of brickwork were built vertically upwards at both ends; the remaining ten, as seen in longitudinal elevation, were diminished by half-brick footings, so that the beam was not so long at top as at bottom, where it measured 25 feet 7 inches in length. This beam was loaded with iron weights piled on the centre of the top of it, which were gradually increased from the month of December, 1835, about two months after it was finished, until the end of March following, when it broke down under a total weight of 27,025 lbs. Several cracks had previously taken place, the first in January, 1836, after 11,147 lbs. had been applied.

(226) Another experimental brick beam was afterwards constructed at the suggestion of Mr. Brunel, by Messrs. Francis, at their Cement Manufactory, Nine Elms, Vauxhall, which remained standing for more than a year and a half. It rested upon two brick piers, at a clear interval of 21 feet 4 inches apart, the whole being built with mortar composed of equal measures of cement powder and clean sharp sand. The piers were 6 feet high above the level of the ground, and the upper part of each was 2 bricks or 18 inches wide, longitudinally, as seen in the side elevation of the beam, and 2½ bricks or 1 foot 10½ inches thick, transversely. Their foundations were bedded in the ground, above which the lower part of each being built with footings, they were more substantial at bottom than the dimensions above specified, especially in section, as measured transversely.

The beam resting on these piers was 2½ bricks or 1 foot 10½ inches wide for six courses of bricks, 18 inches in depth, and its length in this space was equal to the extreme distance from out to out of the piers (24 feet 6 inches), above which it was 2 bricks (18 inches) wide for thirteen courses of bricks (4 feet 9 inches) in depth, thus making nineteen courses of bricks, or about 4 feet 9 inches in all, for its total depth.



Section.



Eleaation of Messrs. Francis's Brick Beam.

This beam had fifteen pieces of 1¼-inch hoop-iron bond, laid longitudinally on the joints; namely, three ton each of the four lower joints, two on the fifth, and one on the sixth, as shown in the section. It was built on planking, which bent about one-eighth of an inch in the centre, and thereby caused the appearance of deflection, though none in reality took place. This planking was removed in ten days, and after the cement was three months old, the beam was loaded with 11,200 ℔s. of scrap-iron, which weight was gradually increased in three months more to 24,000 ℔s., laid upon a sort of scale board under it, suspended by iron bars and chains, from woodwork resting on the top of the beam. In this state, in which I first saw it, it remained for more than a year, until the ground was required for the Metropolitan terminus of the London and Southampton or South-Western Railway, when it was determined to ascertain its final resistance by adding iron rails, in addition to the above-mentioned weight, until it should break down; which was done on the 24th of February, 1838, in the presence of many scientific and professional gentlemen, who had been invited to witness this interesting experiment.*

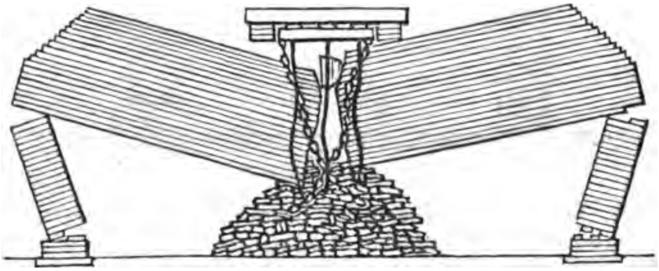
Not being able to attend myself, as I wished, I was informed on inquiry that no crack was observed until the downfal of the beam, which suddenly took place, in the course of two hours after they commenced laying on the iron rails, when the weight thus added had increased the amount to 50,652 ℔s. (or 22 tons 12 cwt. 1qr.) The permanent weight of 24,000 ℔s., previously resting so long on the beam, had not produced the smallest crack, nor had it, in the slightest degree, increased the apparent deflection, caused by the bending of the plank.

In falling it broke into three parts, two of which were nearly equal, each consisting of almost one-half of the beam, whilst the third, near the top, was a very small irregular lump; the fracture, which commenced vertically from the bottom upwards, nearly all along the middle of the beam, having, when very near the top, diverged into two branches in the form of the capital letter Y, which I think must have been caused by two parallel cross timbers, near the centre of the top of the beam, bearing equal portions of the weights, which were not suspended from one central piece of wood, as in the brick beams experimented upon by me, in the manner that will afterwards be described.

The appearance of the brick beam after being broken down is represented in the following figure. The apparatus for bearing the weights, on coming to the ground, had prevented the entire downfall of the parts, and the small lump before mentioned having got jammed in between the two large fragments, prevented them from descending equally low. The piers were fractured and forced out of their perpendicular, and if the fall of the beam had not been arrested, they would no doubt have been pushed entirely over.

---

* Amongst the company present were Mr. (now Sir Isambard) Brunel, Mr. (now Sir John) Macneill, Messrs. Braithwaite, Fox, Erickson, Donkin, Bramah, Field, Cottam, and other Civil Engineers or Mechanists; Messrs. Sydney Smirke, Hardwick junior, and Taylor, Architects; Mr. Manby, now Secretary of the Institution of Civil Engineers; Messrs. Lowe, Herepath, and others.



Elevation of Messrs. Francis's Beam, broken down.

The two large portions of the beam were perfectly sound, excepting a few very small cracks near the great fracture; and no injury whatever had been done to it by the frost.*

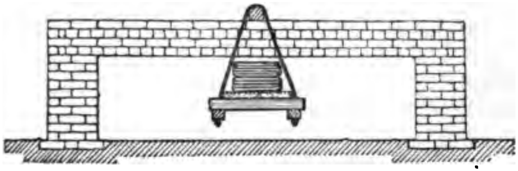
EXPERIMENTS ON THE RESISTANCE OF BRICK BEAMS BUILT WITH NET CEMENT, WITH AND WITHOUT HOOP-IRON BOND. GREAT IMPORTANCE OF THIS BOND.

(227) In order to ascertain how much of the extraordinary resistance of brick beams built with cement, such as have just been described, might be owing to the hoop-iron bond, the following experiments were tried at my request, by special permission and authority of the Honourable Board of Ordnance.

1st. We built a brick beam with net cement, two bricks wide and four courses of bricks high, upon two brick piers built with cement and sand mixed in equal measures, each of which was 2 feet 6 inches high and 2 bricks square above the level of the ground, below which there was one footing or foundation course 2½ bricks square, bedded in common mortar, with the earth well rammed.* The beam, which was 18¾ inches wide and 12 inches high, measured 13 feet 1 inch in extreme length, with a clear interval of 10 feet between the piers, to which it was united by joints of net cement, as represented in the annexed figure, which shows also the apparatus afterwards used for breaking it down.

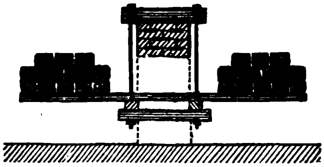
---

* The figures relating to their brick beam were all supplied by Messrs. Francis: the elevation in page 163 about a year before it was broken down, whilst loaded with 24,000 lbs. only; the two others afterwards, when more than double that weight had been applied. The woodwork above the beam differs in the two elevations, probably from an increased apparatus for bearing the additional weight having become necessary in the mean time; but the discrepancy between their figures, as regards a few pieces of woodwork only, which Messrs. Francis cannot now account for, does not in the slightest degree affect the results of this very important experiment, every thing else having been accurately described, and in ample detail.



Elevation of an Experimental Brick Beam.

2dly. We built another brick beam precisely similar to the above, but with the addition of 5 longitudinal pieces of hoop-iron, extending the whole length of the brickwork, two of which were placed in the lower joint, one in the centre joint, and two in the upper joint of the beam, as represented in section, in the following figure, which also shows the breaking apparatus before mentioned.



Section of an Experimental Brick Beam.

3dly. We constructed a third beam similar to the last in every respect, excepting that the brickwork was built with mortar, composed of 3 measures of sand, mixed with 1 measure of well-slaked Halling lime putty, of a stiffish consistency.†

---

* In the two piers we used 189 bricks, 2·8 cubic feet of cement powder, and 2·8 cubic feet of sand. Thus the quantity of cement was rather less than 26 cubic inches per brick, and was in the proportion of ⅕th nearly of the whole mass of brickwork in those piers, the sand and cement together measuring originally about ⅖ths of the said mass, of which they afterwards formed a part. In the brick beam we used 272 bricks, and 7·11 cubic feet of cement powder, which was therefore at the rate of rather more than 45 cubic inches per brick, and was in the proportion of rather more than one-third of the whole mass of brickwork afterwards composing the beam, which was finished in 8 hours by two bricklayers and two labourers.

† In this beam were used 272 bricks, 7·11 cubic feet of sand, and 2·37 cubic feet of Halling lime putty, so that the sand alone measured rather more than one-third, and the lime putty rather more than one-ninth of the whole mass of brick-

We removed the woodwork upon which the 1st and 2nd beams had been built, in 10 and in 7 days respectively, after they were finished, and at the end of 50 days we applied weights to break them down, which were laid upon strong planks placed on a sort of scale board below the beam, suspended by means of two bent pieces of iron passing over both ends of a transverse bar of wood, resting on the centre of the top of the beam. The planks, by projecting considerably beyond the sides of the piers and beam at both ends, allowed the iron weights to be applied without interfering with the brickwork.

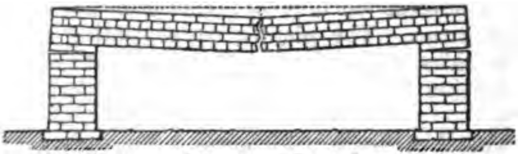
(228) The first beam, which was built with net cement, without the aid of the hoop-iron bond, gave way under a total weight of 498 ℔s. only, including that of the apparatus which has just been described. But the two lower joints had been cracked entirely across the soffit, before any weight was laid upon the beam, which therefore was not a perfect one. This crack, which was very fine, had not been observed until a day or two before the experiment, which consequently was not a fair one; but the circumstance sufficiently proves that the centering was removed too soon, and that a brick beam of the above dimensions, built with net cement, is precarious. In falling, this beam broke into three pieces, of which the centre one was not quite 3 feet long, and the other two differed in length by about 10 inches. One of the two fractures agreed with the original crack that has been mentioned, and was about 1 foot from the centre of the beam.

(229) The second beam, built also with net cement, but having the advantage of the five pieces of longitudinal iron bond, showed a deflection of 1-tenth of an inch when loaded with a total weight of 2537 ℔s., which gradually increased to 2-tenths under a weight of 3718 ℔s., and at this time there was a crack across the two lower courses of the beam. When 3945 ℔s. were laid on, the crack extended to the 3rd course of the beam, and the deflection had increased to 5-tenths. With a weight of 4308 ℔s., the deflection was equal to 1 inch, but with a weight of 4523 ℔s., the crack extended entirely across the beam, throughout its whole depth, and the scale board supporting the planks on which the weights, consisting of iron ballast, were applied, fell to the ground. On removing these weights and the whole apparatus, the beam appeared

---

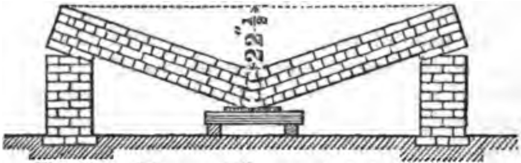
work of the beam. The ingredients composing the mortar therefore originally measured rather more than four-ninths of the said mass, of which they afterwards formed a part. This beam was built by the same two bricklayers and two labourers in 10¼ hours.

in elevation as shown in the following figure, with its centre 4 inches lower than the ends. In consequence of the beam being bedded with net cement on the tops of the piers, it tore off the uppermost course of brickwork of each pier, which adhered to the ends of it, separating themselves entirely from the remainder of their respective piers.



Elevation of the second Beam fractured.

We next raised the apparatus for the weights higher, by supporting the bar of wood upon two pieces of iron ballast, laid on each side of the fracture at the top of the beam. This enabled us to apply weights again, which rather proved the strength of the hoop-iron than of the brick and cement-work, the latter having been already completely fractured; and on increasing our weights to 4314 lbs., the beam again broke down, and fell as low as the scale board beneath it would permit; and at this period the centre of the beam was 22½ inches lower than its ends, as shown in elevation in the next figure, which represents its state after the weights and all the breaking apparatus, except the scale board, which prevented it from touching the ground, had been removed.



Elevation of the second Beam entirely broken down.

On examining it, we found that the centre iron was bent, and the parts of the brickwork there, though fractured, were in contact or nearly so; but the two lower irons had been broken, and the brickwork there had opened out considerably, and two small irregular vertical cracks showed themselves, one on each side of the principal fracture, and a few of the lower course of bricks had been broken off in this part, probably by the violent action of the two irons when broken. In the upper part of the beam, which had been subject to compression, the bricks in the centre were forced violently against each other and crushed, and the two upper irons were buckled but not broken.

Thus the first brick beam, built with net cement, appears to have been scarcely capable of supporting its own weight, from having been deprived of its centering, when only 10 days old; for being thereby injured, when its strength was tried after the cement was 50 days old, it broke down under a weight of 498 lbs.; whilst the second beam, strengthened by the hoop-iron bond, required nine times that weight before it was fractured, and even then only fell 4 inches in the centre, being held together by the hoop-iron.

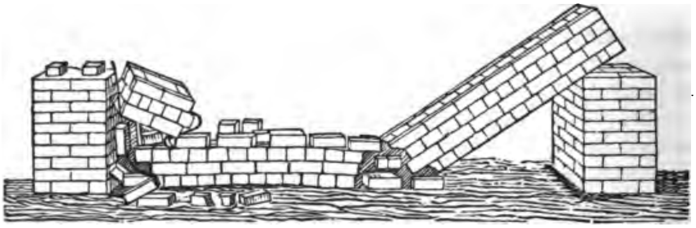
(230) In trying these experiments we did not wish to produce any extraordinary results, but to ascertain a doubtful point of some importance, and therefore we did not give to any of our beams such dimensions as would have required very enormous weights to break them down, like those made by Mr. Brunel and Messrs. Francis. Insignificant, however, as the weights that cracked and finally fractured our second brick beam, may appear, it was not in reality weaker, in proportion to its dimensions, than either of the above.*

(231) The woodwork supporting the third beam was removed in 42 days after the brickwork had been finished, but, observing next day, that a perceptible though small deflection had taken place, we replaced it, until the mortar was 50 days old, when we finally removed it, and subjected this beam to the same breaking apparatus as the others. The original deflection at this time was nearly a quarter of an inch, which on loading the beam with 700 lbs. increased to 3-tenths of an inch, and on adding 42 lbs. more, the beam broke, and the loaded scale board came in contact with the ground. On removing the weights and all the apparatus for supporting them, although there was now a complete fracture through the centre of the beam, it had no tendency to fall lower, being held together by the hoop-iron, but the centre of it had sunk 6 inches lower than the ends, so that it was apparently nearly in the same state as the second beam after its first fracture; but on examination, we found that the whole of the irons had been drawn inwards, from their original position on one side of the beam along the joints of the mortar, to the depth of more than an inch and a half from the end of the beam on that side, with which they had originally been

---

* The comparative resistance of beams of the same materials is stated by a popular rule, to be inversely as their lengths and directly as their widths and as the squares of their depths. Hence if the above rule be considered sufficiently correct to afford a rough estimate approximating to the truth, the comparative strength of Mr. Brunel's beam which was only 6 times, ought to have been 8 times, and of Messrs. Francis's 11 times greater than mine, as was actually the case.

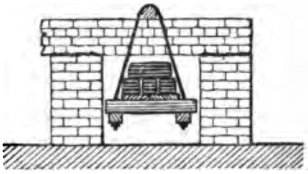
flush. In this state we loaded the beam with pig-iron ballast piled over its centre, until it broke down under a weight of 361 lbs., when that half of the beam in which the irons had been drawn from their original position fell almost all to pieces, every joint of the greater part of it being broken or injured, whilst the other half of the beam, in which the irons had not been moved, held together in one compact mass, of which the greater part was apparently uninjured. None of the irons were broken in this experiment, but those belonging to the weaker end of the beam were violently bent and contorted. The annexed figure is a view of the beam, when thus finally broken down. One of the piers was moved out of its original perpendicular position, and separated a little from the ground on one side of it by the action of the beam in falling.



View of the third Beam when broken down.

(232) This experiment, compared with the two others, proves the great importance of the hoop-irons, for the brick beam built with common mortar could not possibly have held together without them at all; but by their aid, it proved stronger than the brick and cement beam first experimented upon, although if the supports of both had been kept standing for the same period, the latter might perhaps have had the superiority. But although of some value even with common mortar, the circumstance of such mortar not having tenacity enough to prevent the iron bars from being drawn along the joints, when acted upon by a moderate force, after which they cease to be an efficient bond, is an objection to this combination. But when hoop-irons are used to strengthen a brick beam built with net cement, the mutual adhesion of the cement and of the irons is so perfect, that no force can separate them without producing the complete fracture of the brickwork, which is thus resisted by all the tenacity of the iron.

(233) We next experimented upon the most perfect fragment of the first brick and cement beam, by laying it upon



two piers at the clear distance of only 3 feet apart; and applying the same apparatus, we loaded it in the usual manner, as represented in the annexed figure, when it broke under a weight of 2356 lbs.

(234) We experimented also in precisely the same manner upon the most perfect half of the third or brick and mortar beam, which we laid upon two piers at the clear distance of 2 feet 2½ inches apart, but not having room for our former apparatus in this narrow space, we laid one single piece of iron ballast transversely across the centre of the beam, upon which we built others, projecting beyond it, in alternate courses longitudinal and transverse. On applying 4887 lbs., two bricks fell out from the bottom of the beam; when the weight was increased to 4993 lbs., a third brick also fell; and on increasing it to 5147 lbs., the beam fell to pieces. Thus this portion of the Halling lime mortar beam appears to have been stronger in proportion even than that of the net cement beam, owing no doubt entirely to the advantage of being bonded by the hoop-iron.

THAT CEMENT BOND MAY BE USED IN BUILDINGS, IN PLACE OF TIMBER BOND, AND TO THE DISUSE ALSO OF WOODEN LINTELS.

(235) Sensible of the disadvantages of internal bond timbers, let into walls, flush with the surface, the most eminent British architects have recently abandoned this construction altogether, substituting chain bond timbers instead of them, which, being buried in the middle of walls, are not exposed to fire, and if they should decay, the wall will evidently be much less weakened than by a like failure of the former. These timbers are generally so placed as to form part of the lintels over the tops of rectangular doors and windows. This construction was considered very promising at the time, but I am informed that dry-rot has resulted from it in a few years, at least where fir or even English oak have been used. I believe that teak alone has remained sound in this confined situation, and probably Payne's Patent Process would render other sorts of wood no less durable; notwithstanding which it appears to me, that four or five courses of cement bond, that is, of bricks laid in net cement immediately over the apertures of doors and windows, strengthened by hoop-iron in the joints, and continued entirely round the walls of a building at the

same level, will have all the advantages of the common lintels and of chain bond, without any of the disadvantages of woodwork; a conclusion that may justly be drawn from the foregoing experiments on brick beams.

In using hoop-iron bond in walls, the irons should extend if possible the whole length of each wall in one piece; but if a break be necessary, the adjoining ends need not be united together by the blacksmith, but turned down at right angles into one of the vertical joints of the wall by the bricklayers themselves. Without hoop-iron bond, on the contrary, the additional strength communicated by cement alone would not suffice in difficult cases.

It is to be observed, however, that a continued string of four or five courses of cement and hoop-iron bond, in the walls of a building, would not by any means be exposed to the same strain as our experimental brick beams; for it would not have to bear much more than its own weight in all the unsupported parts over a door or window, there being other windows above these; and in all the intermediate portions of the wall corresponding with the ends of our experimental brick beams, the courses of cement bond alluded to would not only be supported from below, but their strength would be greatly increased by the weight of the solid parts of the wall above, it being well known that all beams have a much greater resistance when firmly fixed than when merely supported at their ends, which Mr. Barlow, in his able and useful Treatise on the Strength of Timber, &c., estimates from his own and other experiments as being in proportion to the numbers 3 and 2. Besides which, 10 feet between the bearings is a much greater width than would be given in practice to the windows, or even to the doors of the largest buildings, unless the latter were carriage gateways, which are more usually covered by semicircular or elliptical arches, than by flat arches or straight lintels.

It only remains further to remark, that the flattest and thinnest brick and cement arch has sufficient power to resist great pressure, in openings of 10 or even 15 feet, as was proved by one of our former experiments (134); though a straight brick and cement beam is not to be recommended over such openings, unless consolidated by hoop-iron bond.

Another proof of the extraordinary strength of net cement is the system which has been introduced of using it to unite plain tiles together for the covering of roofs, whether flat or in the form of segmental arches, and also for area vaults in lieu of brick arches.

OF FLAT ROOFS COVERED WITH PLAIN TILES AND CEMENT.

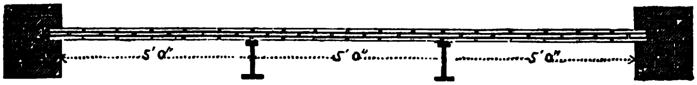
(236) I believe that the first roofs of this description were proposed by the late Mr. Smart, who, by cutting and notching the wood in a very ingenious manner, formed a pair of very flat rafters and a tie-beam out of a single piece of scantling, with the addition of a small oak block, to connect the heads of the two rafters, and two small oblique struts of fir, one on each side of the centre. The very flat trusses thus formed being placed at moderate intervals apart, he covered the whole with two or three courses of plain tiles, laid in cement. Mr. Hight, a builder, of Dover, constructed several roofs of this description, which he showed and explained to me, in 1827, when occupied in extending the Marine Parade at that place, by building new houses to the eastward, along the beach. In his own house, the bearings between the walls were 18 feet, for which he used deals of 2½ by 9 inches, formed into flat trusses on Mr. Smart's principle, and placed at intervals of two feet apart. Over these he laid transverse battens of 2½ by 3 inches, at central intervals of about 10½ inches apart, to support the joints of the lowest course of plain tiles, of which he used two courses for common roofs, but three courses for a flat terrace over the King's Arms Library, at the same place, which people were to walk upon. I understood, at the time, that in this construction he had adopted Mr. Smart's system in all its details.

Mr. Charles Fowler, then Honorary Secretary of the Royal Institute of British Architects, has described, in the first volume of their Transactions, in a paper read to the Society in 1836, a more perfect system of forming flat roofs on this principle, by substituting cast iron bearers instead of wood, which is liable to bend or shrink.* Amongst other examples, he has described the construction of the roofs of two taverns facing the Thames at Hungerford Market, in which three courses of plain tiles, laid in net cement, were supported by cast iron joists, 8 inches deep, with flanges at top and bottom, 3 inches wide, placed at central intervals of 3 feet 8 inches apart.

The longest of these iron joists were 13½ feet nearly in length, the others being shorter, because the cast iron girders of greater scantling, on which they rested, were not equidistant. Laths were used to support the first courses of tiles whilst being placed, which were removed in about half an hour, and used for the same purpose in another part of the roof whilst in progress. There is a staircase leading to the top, where persons who frequent these taverns may assemble in summer, tables and seats being provided for their accommodation; and on particular occasions, as at the opening of the market, and when processions or boat-races take place on the river, the roofs of these taverns, as well as of terraces at the same market, also constructed by Mr. Fowler, but at intervals of 4½ feet between the iron joists, have been crowded by as many persons as could stand upon them, without danger. But the most extensive flat roof of this description that I am acquainted with, has been constructed by Mr. Brunel, over a detached room on the park side of his house, 18, Duke Street, Westminster, in which he employs draftsmen and clerks. It is 40 feet long by 20 feet wide, and was covered at first by two courses of tiles in cement mortar, composed of two parts of cement to one of sand, to which, as it showed symptoms of weakness when a great mass of earth was laid upon it, for a purpose afterwards abandoned, a third course of tiles in net cement was added. This terrace is supported by six strong cast iron beams, extending transversely the whole width of the room, and eight short longitudinal ones, four at each end; the former resting on opposite walls, the latter supported partly by the end walls and partly by the two adjacent beams. The whole of these supports are placed at central intervals of 5 feet apart. The principal cast iron beams are about 14 inches deep in the centre, but diminish several inches towards each end, and thereby afford sufficient slope each way to carry off the rain-water. They were cast with flanges at bottom, and openings above these flanges to diminish the weight, by means of which openings a ceiling has been attached to them, without which they had proved intolerably hot in summer and cold in winter. This is therefore a necessary appendage to all flat roofs of this description, over inhabited apartments. In several of the houses of Norfolk Crescent, Hyde Park, the back kitchens behind the rear walls have been covered with flat roofs of this description, in which cast iron beams have been used, to some of which I am informed that wrought iron bars on edge have been attached at right angles, and resting upon them to support the tiles, but the whole are concealed by the ceilings of those kitchens. This arrangement, however, appears unnecessary, unless the distance between the principal beams should exceed the width at which three courses of tiles, laid in cement mortar or in net cement, can support the greatest possible weight that is ever likely to press upon them, with safety; that is, about 5 feet, as far as our present experience goes, though I think it probable that a greater space might be allowed: but this is a point that experiment only can determine. For covering narrow spaces, such as an open area in front of a house, these wrought iron bars are far the most convenient, because they save the necessity of having iron beams cast on purpose. For example, I have had part of an open area of my house in London covered in this manner, by bars only half an inch thick and about 2¾ inches in depth, at bearings of 7 feet 3 inches; and it does not appear that terraces or flat roofs resting on such narrow surfaces as the above are weaker than those supported by flanges of 2 or 3 inches in thickness.* Where the situation prevents windows from being made in the walls, as, for example, in this covered area and in the back kitchens of the houses before mentioned, skylights of thick glass have been provided, either with wooden or iron frames, of which the latter are preferable. The annexed diagram represents in section a flat roof, such as has been described, supported by cast iron beams with a narrow flange at top, and a broader one at bottom, by means of the latter of which it is obvious that a ceiling could easily be added.

---

* Sir Isambard Brunel's brick beam (225) has been minutely described, with explanatory drawings, in the same volume.



Section of a Flat Roof of plain Tiles and Cement.

This construction appears to be a great improvement, and might be adopted with advantage in those parts of India, as well as in Malta and other countries, where flat roofs are almost exclusively used, which, being supported by beams of timber, are liable to troublesome leaks in consequence of the bending or shrinking of the wood.†

Of Mr. Frost's Tubulated Floors and Flat Roofs.

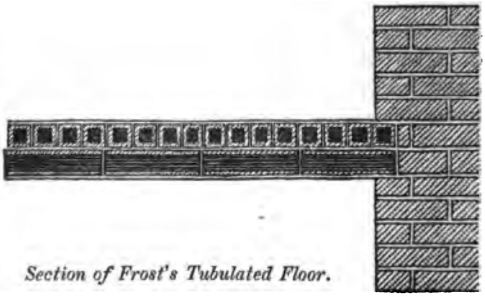
(237) This ingenious gentleman contrived a sort of earthenware tubes, measuring 2½ inches square externally, and made

---

* The entrance portico of the Black Lion Tavern, Bayswater Terrace, is supported by cast iron pillars, over which there is a cast iron beam in front, between which and the opposite wall of the house are laid wrought iron bars, supporting a terrace of three courses of tiles in cement, on which persons sit in summer, under an awning, and which will bear as many as can stand upon it.

† In Calcutta and the neighbourhood, the flat roofs are supported by strong

by a machine in lengths of 10 feet, but cut previously to being baked, into pieces only 1 foot long. Two courses of these laid in net cement, at right angles to each other, form a floor or roof 8 or 10 feet wide, of which specimens may be seen at his late Artificial Cement Works, now the property of Messrs. John B. White and Sons. Mr. White has a very favourable opinion of this contrivance, which he considers a safe floor for any number of men to walk upon, at the above width. In consequence of the tubulated form of its component parts, a floor or roof of this construction may perhaps be rather stronger than one made of plain tiles, or any other sort of flat tiles, of equal weight; but as the latter are an article of commerce, that can be procured every where, they are not likely to be supplanted by tubes, which must be ordered on purpose, at a much greater expense. The following figure represents a portion of one of Mr. Frost's tubulated floors in section, showing at one end its connection with the wall. These tubes are so arranged as to break joint with one another in both courses, and cement stucco is applied above and below them.


Section of Frost's Tubulated Floor.

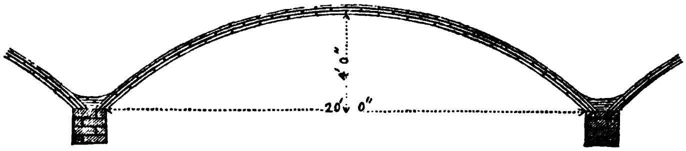
---

beams resting on opposite walls, at intervals of 3 or 4 feet, over which are laid longitudinal rafters of about 3 by 4 inches, at central intervals of 1 foot apart, upon which are laid paving tiles 1 foot square and 1 inch thick, covered by a second course of similar tiles breaking joint with the former. Small fragments of broken bricks or tiles are then applied, and by adding quick-lime and water, are formed into a sort of concrete, called *Coah*, 6 or 7 inches thick, which is well beaten with small mallets, and over all is applied a fine coat of cement of lime and tile-dust, made quite smooth, and sometimes rubbed over afterwards with oil. In the upper provinces of India, long stones are used from beam to beam, instead of rafters and tiles. The flat roofs in Malta are similar to the latter construction, strong beams, nearly square, being laid from wall to wall at clear intervals of 3 feet, upon which are laid long stones about 3 inches thick and 1 foot wide, which are covered by a mixture of small broken stones and tough red argillaceous earth, formed into a sort of concrete with water, and well beaten. The surface is then coated with a cement made of lime and puzzolana, or of lime and fine tile-dust. The stones, of a calcareous quality, nearly resembling Bath stone, have very little tenacity, but when protected by the elasticity of the superincumbent mixture, they will bear the weight of as many persons as can stand upon the roof, which may be about 8 or 9 inches in extreme thickness above the beams which support it.

OF SEGMENTAL ARCHES OF PLAIN TILES AND CEMENT FOR ROOFS, &c.

(238) This construction, consisting of three courses of plain tiles laid in net cement or cement mortar, has been adopted for the workshops on the south side of Titchborne Row, between Titchborne Street and Burwood Mews; which being of considerable length, and depending on two parallel walls only one brick thick, with internal pilasters increasing the thickness to 1½ brick at central intervals of 10 feet, have been strengthened by iron tie-rods passing through opposite walls near the springing of the arch, in every pilaster, which tie-rods have right and left-handed or contracting screws in the middle of each, where it is connected with a vertical rod from the crown of the arch. There are two parallel rows of workshops with roofs of this sort, the widest of which has a span of 20 feet 8 inches, with a rise of 4 feet. To introduce tie-rods with contracting screws is always prudent in long roofs of this description, but for roofs laid out in a series of arches depending on transverse walls as piers and abutments, such as the roofs of stables in the same neighbourhood, tie-rods have been deemed unnecessary. The forage lofts above the stables alluded to have been lighted by skylights having wooden or iron window frames on one or both sides of the crown of the arch, but the apartments occupied by the coachmen or grooms have ceilings under the arched roofs, and are lighted by common windows. In the workshops, where a great number of joiners were employed, they complained that these arched roofs, being air-tight, became damp from their breathing; and on raising the upper story of a parochial school at the end of these workshops, the same inconvenience having been experienced under the original arched roof, caused it to be pulled down, and a common roof substituted. It might, however, in all cases be avoided by having openings for ventilation in the centre of the roof, covered so as to exclude rain, whilst they admit air, as Mr. Brunel has introduced in his office, before mentioned.

The following figure represents, in section, part of a range of buildings roofed in this manner, by flat segmental arches, having a rise of one-fifth of the span, which seems a good proportion, though perhaps the minimum that should be allowed.



Section of part of a Range of Arched Roofs of Tiles and Cement.

In this construction the gutters are carried along the transverse party walls, as in the figure. Specimens of arched roofs may be seen in part of the stables of Torrington Mews, Burwood Place, and of Devonport Mews in rear of the west end of Oxford Terrace, the latter having a span of 21 feet, with a rise of 5 feet 9 inches.

Plain tiles being 6 by 10 inches square, and rather more than half an inch thick, the custom, in building arches with them, such as have been described, is to place the first course of tiles transversely, so that the section of the under side of the arch is a polygon, having sides of 10 inches, at which distance longitudinal battens are laid over the centres to support the first course, with which the second course ought every where to break joint, and so also should the third with the second. Three courses of tiles are always used, which in spans of 20 feet or a little more are sufficiently strong for every necessary purpose. I have heard of much wider roofs of this description, in which more than three courses of tiles may probably have been used, but I have never myself seen any exceeding 21 feet in span.

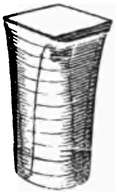
Three courses of plain tiles and cement, generally having lath-and-plaster ceilings under them, have also been used for covering the porticos of the houses in many of the handsome new streets and squares in the parish of Paddington, near Hyde Park. From the moderate dimensions of such porticos, intermediate bearers of wood or iron are unnecessary, but hoop-iron bond should be used in the brickwork over the heads of the columns, for connecting them with each other and with the front wall. In the same neighbourhood segmental arches of three courses of tiles and cement have been generally used for area vaults,* for the communications over the area to the front door of each house, and for carriage gateways leading from the street to the mews or stables in rear of the houses.

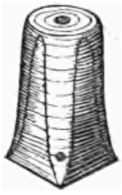
---

* In one of the new streets near the Paddington terminus of the Great Western Railway, the area vaults of this description are segmental arches of 9 feet span, with a rise of only about 18 inches, the piers or intermediate walls having the usual thickness of 1½ brick. Earth has been laid over these vaults to the height of 4 inches above the crown of each arch, at which level the flagstone pavement will be laid. These vaults, though I have no doubt they will prove strong enough, are unusually flat, as compared with the more common area vaults, usually

OF FIRE-PROOF CEILINGS OR FLOORS FORMED BY ARCH POTS AND CEMENT.

(239) Fire-proof ceilings and floors, or rather ceilings and floors so styled, have often been made by flat segmental arches in cement between cast iron girders; and to save the weight of solid brickwork, the use of which, in dwelling-houses having wooden floors over such arches, has been deemed superfluous, *Arch Pots* or *Hollow Cones*, as they are more usually, but I think improperly termed, have been used. These arch pots, at least such as have been made in England, are square at top and circular at bottom, the sides of the squares and diameters of the circles being equal. Of those which I have seen, the largest were 8 inches high and about 4¾ inches square at top; the others were from 5 to 5¾ inches high and about 4¼ inches square at top; the former weighing about 4¼ ℔s., and the latter about half as much; and when formed into an arch, the small pots are said to weigh about two-thirds of a half-brick arch of the same span.





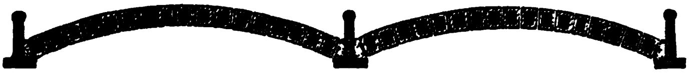
The first of the annexed figures represents one of these hollow cones seen in the position in which it is used with the square end upwards, whilst the second represents it turned upside down. The sides and bottom are scored, and a small hole is usually made in each previously to these pots being baked, in order to afford a key for the cement or mortar used in constructing the arch, as well as for the plaster, when the ceiling is not an ornamental one beneath these arches, but formed by plastering the under surface of the pots themselves.

Arches of this description were used for ceilings over the basement story of the new Treasury Buildings, Whitehall, by Mr. Soane; and over that of the Union Club, by Sir Robert Smirke; for the floors of the National Gallery, Trafalgar Square, by Mr. Wilkins; for some of the floors of the United Service Club, Pall Mall; and for all the floors of Buckingham

---

covered either by segmental arches of much greater rise, or even by semicircular arches, and composed of one or even two half-brick rings, measuring together 9 inches in thickness.

Palace, by Mr. Nash,* in the manner represented in the annexed figure. Various expedients, such as pieces of brick or half pots broken down the middle, alternating with the regular arch pots, were used, in order to obtain proper bond at the springing of these arches, which generally abutted against stone skewbacks on each side of the iron girders, as shown in the foregoing section. The span of these arches was usually about 6 feet, seldom more than 7½, and never less than 4½ feet, and their rise seldom exceeding 6 inches.



Section of a Portion of Fire-proof Ceiling or Floor.

OF FIRE-PROOF PARTITIONS.

(240) As upper apartments are usually smaller, especially in the attic story, than those below, partitions in those stories are not always supported throughout their whole length by the internal walls of the building. They usually consist of a wooden framework, lathed and plastered on both sides, and so braced as to press lightly on the floors below, when there

---

* In the floors of Buckingham Palace the boarding is laid upon very long bridging joists of 3 by 6 inches, notched one inch down over the tops of the iron girders and supported by light frames of wood, consisting of a sill and cap, extending the whole length of the floor with uprights at intervals of 4 feet, the sills of each pair of such frames resting upon the springing of the arches immediately over the flanges of every girder. The ceiling is suspended by square iron rods passing down through iron plates over the crown of each arch at intervals of 3 feet apart, having screw heads and nuts at top, the latter resting on the plates. At bottom, each rod is bent at right angles, in the form of the capital letter L, upon which the ceiling binders rest, and are fixed to the iron by one vertical and one horizontal screw entering the wood. The ceiling joists are nailed to the under side of these binders. In the flat parts of the roofs of the Palace, Mr. Nash employed two tiers of segmental arches of the same description, laid in cement, each 5 inches deep, supported by iron girders, 44 feet long, having a span of 40 feet between the opposite walls, with solid bearings of 2 feet at each end. They are 29 inches deep in the centre, diminishing from thence towards the ends, and have flanges 6 inches wide at bottom. The thickness of iron increased from 1¼ inch at top to 2 inches at bottom, so that the bearings for the arches were 2 inches wide on each side of the upright stem of the girder. Both arches spring from single pieces of Bath stone, fitted to the girders, one on each side, and cut with two skewbacks, one above the other. Over the upper arch were laid whole or broken bricks or tiles with cement mortar, until the general level required was obtained, which was coated with about one inch in thickness, of a composition for terraces or flat roofs, proposed by Lord Stanhope, consisting of Stockholm tar, pounded chalk and sand boiled together, and afterwards covered with paving tiles or bricks laid flat. When I inspected this roof, some years after it had been built, I found that the composition became more fluid under a hot sun than could have been desired, which was, however, of little importance, as it was not used as a terrace for walking upon. In other respects it was satisfactory.

is no wall beneath them, and to resist any action from the floor above, if there be one. Sometimes the interstices of a partition are filled with brickwork, termed *Brick Nogging*, a sort of construction often observable in the walls of cottages, and never more than half brick thick, 4 inches being the usual thickness also of a wooden partition, exclusive of the laths and plastering afterwards added. The experiment of the summer-house, as well as the properties of brick beams built with net cement, sufficiently prove that a half-brick partition, or even a brick-on-edge partition, built with net cement and hoop-iron bond, and bonded into the walls on each side also with cement, which would support its ends, would not exert any unfavourable pressure downwards, in the intermediate space between those walls; and at the same time it would be fire-proof, which is not the case with any common partition.

OF THE ADVANTAGES OF USING CEMENT FOR CHIMNEYS.

(241) The withes or partitions between the flues of chimneys, as well as the chimney breasts, and frequently the boundary walls or external withes of chimney shafts, being only half brick thick, the superior strength that will be obtained from laying such thin brickwork in cement will be obvious. The accidents destructive to property and sometimes to life, from high chimney shafts being blown down in gales of wind, will be prevented or rendered much less frequent, and so far as regards chimney breasts, the propriety of coating them towards the apartments by vertical courses of plain tiles fixed in cement, and breaking joint with the brickwork, has been suggested, which will obviate the risk of flame penetrating through the joints of the half-brick wall, and setting the house on fire, which has at times been known to happen.*

OF THE EFFECT OF FIRES ON BUILDINGS. THAT STONE FLOORS COMBINED WITH CAST IRON GIRDERS AND PILLARS DO NOT DESERVE THE NAME OF FIRE-PROOF.

(242) Having attentively considered the effect of great fires on houses and other buildings of the usual construction, for the fire-proof floors and ceilings described in some of the preceding articles are by no means common, I have invariably found that good brickwork seems to be a perfectly fire-

---

* This expedient was suggested to me in conversation by Mr. Baker, of Russell Square, and of Stangate Wharf, Lambeth, whose skill and experience as a builder are well known.

proof material; but from the injudicious system of supporting the upper part of the walls of shop fronts by wooden bressummers and story posts, and of letting bond timbers and wall plates and the ends of wooden girders and joists into the walls, it seldom happens that the woodwork of a building in England is burned, without its becoming necessary to pull down the greater part, if not the whole, of the brickwork also. Even in new buildings, more judiciously constructed, and exposing less superfluous woodwork, I have observed, after several great fires, that parts usually considered fire-proof have failed. For example, strong cast iron columns and beams are usually cracked or broken, in consequence of having first been exposed to a red heat and then suddenly cooled by streams of water from the fire engines; and I have also observed, that large stones in buildings, when exposed to a strong fire, are invariably injured and defaced by fragments detaching themselves from the surface. Hence, when a warehouse is constructed with iron pillars and beams, supporting stone floors, it cannot be considered fire-proof, unless when filled with incombustible goods; for if the contents of such a building were to take fire and burn briskly, the heat will break the stones of the floor, and may even crack or split the ironwork, so as to render it necessary to remove and replace it by new, even if it should not absolutely break down. I am not sure about the ceilings of arch pots before described, but I am persuaded that no fire that can occur in a dwelling-house or warehouse, could possibly injure an arched ceiling of common bricks, though only half brick thick, for as I said before, all brickwork is fire-proof. I have observed, that the interior stucco on brick walls is usually partially detached, and so much injured by fire, that it is necessary to take it off and replace it afterwards; but in the mean time it guards the mortar or cement joints of the brickwork to which it was applied. If these should be exposed, which is always the case when the wall is not stuccod, I have observed that the lime in the calcareous mortar or cement of the joints is burned into quick-lime, to a depth never exceeding one inch, but usually less; so that the greatest penetration of this process is far too insignificant to affect the solidity of the wall, which only requires the damaged mortar to be raked out of the joints, and to be replaced by pointing. Hence I would condemn stone floors for fire-proof buildings altogether, and recommend brick arches in cement in preference, with a flooring of strong paving tiles, not of flag stones, over them: but I shall treat of fire-proof floors for manufactories and warehouses in detail hereafter; only observing, in the mean time, that the fire-proof floors and ceilings of arch pots before described, for which Sir Robert Smirke in some of his last buildings, as at the new Custom House, substituted segmental wrought iron plates, as being lighter, are unsuitable and inadequate for manufactories and warehouses, and have only been used as yet in dwelling-houses and public buildings, to diminish in some degree the risk of fire.

GENERAL REMARKS ON THE SUPERIORITY OF CEMENT OVER LIME MORTAR.

(243) From the various examples of the wonderful power of cement, recorded or alluded to in former parts of this Treatise, it must be allowed, that the use of this admirable material renders many constructions both with stone and brickwork, not merely possible but easy, which with common mortar are absolutely impracticable. It not only does away the thrust of arches, and renders centering of any magnitude unnecessary, but what is more, it even dispenses with the arch-like form altogether, as was proved by the small summer-house (223), and brick beams before described (225 and 226); so much so that I am confident that the present model room in the Royal Military Repository at Woolwich, which is in the form of a round marquee or large tent, might be replaced entirely by brickwork and cement, without any central pillar, such as that which now supports the wooden and canvas roof of that large circular building. In short, there is scarcely any form of covering for the roofs of buildings, that may not easily be executed with brickwork and cement alone, aided by hoop-iron bond, from the stateliest dome of European architecture to the fantastic pinnacles of the Oriental nations.

The superiority of cement has been repeatedly proved, as for example by the downfal of the numerous arches of railway viaducts and bridges, even such as have been built with mortar made of good hydraulic lime, before the railways of which these works formed a part were opened. I believe that this has occurred in almost every railway in the kingdom; and in those failures, which I have examined personally or inquired into, not as a matter of duty, for such works did not come under the cognizance of the railway department of Government whilst in progress, but for my own information, I have always found that the designs and specifications of the engineers were unexceptionable, provided that the work could have been executed with due care, and sufficient time allowed for the setting of the mortar before the centres were struck; instead of which, such viaducts and bridges have usually been run up in haste, the arches often built in rainy weather, saturating mortar otherwise of good quality with wet, the centres struck too soon, and the concrete or ballast over the haunches not having been applied gradually on both sides of every arch, but having often been *shot*, as it is termed, or violently thrown down from barrows or even contractors' wagons, first upon one side of the arch and thus overloading it injuriously, before any was thrown on the other side. In repairing the failures now alluded to, that have come under my knowledge, the new arches, &c., have always been built with cement, which if used in the first instance would have saved much time, trouble, and expense, and sometimes the lives of workmen.*

I also observed in October, 1845, after it had become necessary to enlarge a short tunnel under a high hill on the Newcastle and Carlisle Railway, originally constructed for one line of rails only, by adding to its width and height in order to admit a second line of rails, that the use of lime mortar, which though of good quality, could not set in time to secure the work against the pressure of soil above, consisting of very loose sand, led to a failure that caused much trouble and delay, and rendered it necessary to secure part of the tunnel by adding iron ribs and plates. Had cement been used, the arrangements for enlarging the tunnel without stopping the traffic, which were very ingenious and skilfully made, would have been attended with complete and uninterrupted success. Upon the whole, considering the unfavourable circumstances with which the execution of railway works is often attended, the recklessness of workmen, and the difficulty of proper superintendence on all parts of an extensive line, it would be more judicious for railway engineers to use cement in the construction of their bridges, viaducts, and tunnels, more extensively than they have hitherto done; and in the wet parts of tunnels particularly, in which water filtering through the arched roof gradually dissolves the lime in the joints,* I am of opinion, that cement should be used, not merely in preference to, but to the entire exclusion of, the best lime mortar.

---

* A few examples of such failures shall be stated. In 1845, part of the nine-arch bridge for passing the Ashton branch of the Sheffield and Manchester Railway over the river Thame fell down, whilst the workmen were throwing ballast upon one side of one of the last finished arches, without sufficient care; and six semicircular arches out of twenty-four, of a fine brick viaduct bridge on the Tonbridge Wells branch of the South Eastern Railway, also fell suddenly, soon after the centres were struck, though the arches had the moderate span of 24 feet, and were built with mortar of excellent quality made of grey chalk lime, but unfortunately in very rainy weather, and the piers and abutment on each side of the fallen arches were well-proportioned and strong, so much so, that on examining them soon after the accident, I found that they had not been injured by it in the slightest degree. In 1846, part of the hollow abutment walls of a bridge for passing a turnpike road over the Maidstone and Canterbury branch of the South Eastern Railway fell down in consequence of those walls having been built with common lime, but the arch over the railway stood, having been built with cement. The same year, a dangerous and alarming settlement of the principal arch of the fine brick viaduct over the London Road at Brighton, near the junction of the London and Brighton with the eastern branch of the South Coast Railway, rendered it necessary to pull down that arch and rebuild it. In June, 1847, whilst the Greenwich Railway, now the property of the South Eastern Company, was being widened, in order to lay down two additional lines of rails, by a series of arches, of which all the rest have stood, that which had just been built over Russell Street, Bermondsey, fell down when the two last centres were about to be removed, all the others having been previously taken down, whilst a horse and cart passing had accidentally become entangled with a rope forming part of the apparatus employed in that operation. I examined the masonry soon after the accident, and found the abutment walls uninjured and of ample strength, but the mortar, though made of Dorking lime of excellent quality, not having been allowed time to set, was quite soft. The centres were struck sooner than they ought to have been, as this street, blocked up for the time being, was a great thoroughfare, which it was desirable to restore as soon as possible; foreseeing which, the arch over it ought to have been built with cement, like those nearer to the London Bridge station of the same railway, none of which have failed, nor have any of the other arches, though built with mortar, as the centres were not removed so hastily.

(244) I conceive also that it would be better for engineers and architects to require cement to be used for the segmental brick arches of all fire-proof floors, abutting against cast iron beams; instead of which it has been customary in the north of England to build such arches with mortar, which, however good the quality of the lime may be, requires wrought iron tie-rods from girder to girder to prevent the thrust of the arches from breaking down the floors, until the mortar shall have set, a precaution which is not always effectual; for accidents have been caused by this construction, which could not have happened with cement.

For example, all the floors of a cotton mill of seven stories, belonging to Messrs. Radcliffe and Sons, of Oldham, fell down suddenly on the 31st of October, 1844, owing to a defect in one of the segmental brick arches of the uppermost story, having a span of 11½ feet and a rise of one foot, which having settled four inches at the crown, rendered it necessary to take it down and rebuild it, by portions of one-third of its length at a time; and whilst this work was in progress, the thrust of an adjoining arch acting on one side only of an iron beam, from the other side of which the defective brickwork had been removed, broke that beam, and caused also the fall of the finished as well as of the unfinished arch on each side of it, in consequence of which all the other beams and arches of the same story, though strengthened by iron tie-bars, together with the iron pillars supporting them, gave way also, and falling upon the floors below them, the whole were broken down in succession; and the inside of the mill became a heap of ruins, under which the persons at work in the lower stories were overwhelmed and many lives lost. Had the arches been built with cement, no settlement would have taken place, and as such arches have the properties of brick beams, and exert no thrust or lateral action injurious to stability, the mill could not possibly have broken down under the circumstances that have been stated.

---

* Finding that the lime, though made of good grey chalk having hydraulic properties, was being dissolved, and forming stalactites or falling in drops from several parts of the Fareham Tunnel of the Gosport branch of the South Western Railway, I recommended that the joints of the mortar in all those wet parts of the roof should be raked out for about an inch in depth, and pointed with net cement carefully applied, which would prevent that destructive process.

Secondly. A new building consisting of two stories of three cells each, for solitary confinement at the House of Correction, North Leach, Gloucestershire, covered by segmental brick arches of 7 feet span and 12 inches rise, half brick thick for the lower, and one brick thick for the upper story, with a concrete floor over the former and a concrete roof over the latter, to measure, respectively, 9 inches and 18 inches in depth, including the brickwork, at the crown of each arch, suddenly fell down on the 13th of November, of the same year, before the whole of the concrete over the roof was applied, after very heavy rains that had saturated the concrete and mortar of the roof, though both were made of blue lias lime of the best quality, notwithstanding the iron tie-bars applied over the three arches of the upper story, which were secured to vertical iron bolts let down into the upper part of each wall.

It is scarcely possible to have a more convincing proof of the superiority of cement over the best lime mortar than this failure; for the County Surveyor, under whose superintendence the building was designed and executed, had copied the same construction in every other respect that had been adopted by Major Jebb for the solitary cells in the Model Prison at Pentonville, and which has been followed since in many other prisons, none of which have ever failed, the arches having been built with cement according to the rule judiciously laid down by that officer, in his official report respecting the construction, ventilation, &c., of Pentonville Prison, where no iron tie-bars were used.*

---

* Major (now Lieut.-Colonel) Jebb, R.E., Surveyor-General of Prisons, in his

The fall of this and of the cotton mill at Manchester led to the appointment of Sir Henry de la Beche and Mr. Thomas Cubitt as Royal Commissioners, to investigate the causes of those accidents, to whose official report on the subject, dated the 28th of February, 1845, presented to both Houses of Parliament by her Majesty's command, which with its appendix contains much valuable information, I refer for details. Mr. William Fairbairn, Civil Engineer, and Mr. Belhouse, Architect, of Manchester, both skilful and experienced in the use of cast iron, as applied to fire-proof floors, were of opinion, that if the mill at Oldham had been finished and in full work, the iron beams of the floors would have had to support a constant weight, according to their calculations, not absolutely equal, but so nearly approaching to the weight capable of breaking them, that they could not be considered safe for any length of time; upon which I may observe, that, whatever might have happened afterwards, the immediate and sole cause of the sudden fall and destruction of all the floors of that manufactory was the failure of one of the brick arches of the uppermost story, and not the weakness of the ironwork. If cement had been used, as I before remarked, this failure could not possibly have occurred; and the iron beams, after the whole of the floors were finished, instead of breaking all at once, would have shown before-hand a perceptible deflection, indicating doubtful strength, which, if observed in time, as it could scarcely fail to be, would have enabled the owners to shore up their floors and eventually to secure their beams by intermediate cast iron pillars, in addition to the original ones set up under the middle of each beam, in every story, from the bottom upwards.*

Report on Pentonville Prison, addressed to the Right Hon. Sir James Graham, then Home Secretary of State, on the 18th of August, 1844, states that all the cells for solitary confinement are 13 feet long by 7 feet broad and 9 feet high to the under side of the arched ceiling, the division walls between the cells, which are the pier walls to the arched ceilings over them, being two bricks or 18 inches, and the external walls 2½ bricks thick.

The ceilings of the cells are formed by a half-brick arch grouted in cement, over which is laid concrete, and in some cases earth, about 6 inches in depth, which is levelled so as to receive the surface of asphalte which forms the floor of the cell above. The thickness from the ceiling of one cell to the floor of that above it, is 1 foot. In the upper cells, as a measure of security, the arch is 9 inches thick, in two courses, turned separately in cement, with a layer of hoop-iron at 4-inch intervals laid diagonally between them. With the same view, as the outer walls are rendered hollow by the ventilating flues worked in them, it has been deemed to be a necessary precaution to lay in near the outer surface a single course of hoop-iron every six inches.

* This was actually done, by advice of Mr. Fairbairn and Mr. Belhouse, in another mill belonging to Messrs. Radcliffe, which was completed without an accident, though of the same construction as that which broke down.

THAT THE PRACTICAL MODE OF ASCERTAINING WHETHER A CALCAREOUS STONE WAS A WATER CEMENT OR NOT, AS DESCRIBED IN FORMER PARTS OF THIS WORK, WAS THE BEST THAT COULD BE USED FOR THAT PURPOSE, BUT NOT SATISFACTORY AS APPLIED TO THE WATER LIMES.

(245) My own mode of ascertaining whether a calcareous stone was a water cement or not, was to pound it when burned, to make the calcined powder up into balls with a moderate quantity of water, and to put these balls into a basin of water almost immediately afterwards, when, if the stone experimented upon was a good cement, they set almost immediately into a very hard substance; if not, they fell to pieces. Nothing can be better or more appropriate than this method, which decides the question at once. (45, 46, and 47.)

But the same process, when applied to limes, in order to ascertain their water-setting properties, is by no means satisfactory; for even the blue lias lime, which is the most powerful water lime in England, and probably in Europe, either goes to pieces in time, or does not set in a satisfactory manner, under water, when thus treated, as was stated in Article 24. Smeaton's mode of experimenting upon such limes, to all the details of which I had not properly adverted, when I began to investigate the subject, was much better than mine; but I consider the following process to be better than either, which I have partly borrowed, that is, with modifications, from M. Vicât and General Treussart, two of the most recent and approved French writers on the subject of common and hydraulic limes and mortars, of whose able and important researches I shall endeavour to give a synopsis in the Appendix.

RULE FOR ASCERTAINING WHETHER A LIME HAS HYDRAULIC PROPERTIES.

(246) Burn some of the lime stone in a fire-place for about three hours, until it ceases to effervesce in acids, as directed in Article 45, or if it be a lime in common use, procure some of it well burned and fresh from the kiln, and slake it thoroughly by first pounding it in a mortar, and afterwards working it up into a stiffish paste with water, upon a slab with a spatula. Whilst being thus mixed, it will throw out more or less heat according to its quality. Wait therefore until it becomes perfectly cool, and then put it into the bottom of a cup or small basin, pressing the upper surface of it into a level form, after

which, if it should be rather too moist, let it dry a little, until it becomes a stiffish paste. If it should crack in this state, which can only proceed from the whole of the lime not having been thoroughly slaked, when put into the basin, a circumstance most likely to occur with very powerful hydraulic limes, which slake with difficulty, such as the blue lias,* it must be taken out of the basin and remixed with a moderate quantity of water, and then put back again; after which, let water be poured into the basin until it is nearly full, taking care not to disturb the surface of the lime paste, which will now be completely immersed.

In this state, let the paste be examined daily, by pressing it with the finger, and if it should become so much harder as not to yield to the pressure, it is a hydraulic lime, and has just begun to set. If, on the contrary, the lime paste, immersed in a stiffish state as above directed, should become softer under water, it is a common lime having no hydraulic properties. In comparing several hydraulic limes together, that which sets the soonest after immersion may be considered the most powerful.

In experimenting with the blue lias lime of Lyme Regis, in this manner, we found that it set rather more quickly, when made into a stiffish paste with a moderate quantity of water, than it did when mixed with excess of water into an almost fluid state, but both of these sorts of blue lias lime paste having been covered with water about an hour after they were mixed, attained such a consistency that they resisted the action of the finger next day, and eventually set into a hard substance, especially the former, which had a decided superiority over the latter.† We had before ascertained that the same blue lias lime putty, when these precautions were so far neglected as to immerse it whilst still warmish, without waiting till it had become perfectly cool, would not set under water at all.

(247) On mixing one measure of the same blue lias lime with one measure of sand, and allowing a couple of hours before immersion, this mixture also set under water, though not into so hard a substance, nor so soon as the lime alone had done: but on mixing one measure of this lime with two

---

* See Article 24, and the note to Article 26.

† The last of these, which was mixed in rather a fluid state, adhered so firmly to the cup, that it was impossible to separate them, without breaking the lime, which was not easy, as it had become exceeding tough in setting. All the other experimental mixtures tried in this manner, whether of net lime or of lime mortar, after setting at the surface, always detached themselves from the cup, in cakes of the form of the plano-convex lenses of opticians.

measures of sand, and treating it in the same manner, it became softer after immersion, and would not set at all, at or near the surface; but at the end of two months, after removing about an inch of the surface, which was quite loose, the remainder of it was found to be setting in a slow but satisfactory manner.

REMARKS ON THE INTRODUCTION AND USE OF PUZZOLANA IN ENGLAND.

(248) About the middle of the last century, Trass appears to have been in common use throughout England for all works exposed to the action of water, in the proportion, as Smeaton observes, of 2 measures of slaked lime to 1 of that substance. In respect to Puzzolana, it appears that it had not been used at all in England, and that he only met with it by accident, a merchant having imported a cargo of it from Civita Vecchia, on speculation, which nobody would purchase or even try, till Smeaton experimented upon its qualities, from having read of it in Belidor's Architecture Hydraulique; and finding it superior to trass, and offered by the owner at a lower price, the whole cargo was purchased and employed by him in the building of the Edystone Lighthouse, in which it was mixed with blue lias lime from Watchet, a small port of Somersetshire, in the Bristol channel. The Watchet lime used by Smeaton was burned and also slaked on the spot, with just water enough to cause it to fall down into a fine powder, which was closely packed in water-tight casks and sent to Plymouth, and from thence to the Edystone rock as required; in which state, Smeaton observes that it kept so well, that he used the surplus of the same lime which had been provided in 1757 for the Edystone Lighthouse no less than seven years afterwards, in the most critical part of the works for improving the navigation of the river Calder. At this period, he says that he found the lime in the casks perfectly good, but that he took the precaution of bruising and sifting some parts of it which had become rather lumpy. This mode of slaking lime is equivalent to what was afterwards recommended by M. De la Faye, in France, and which has recently been very generally used there. Smeaton mixed his slaked lime powder and puzzolana in equal volumes, throwing both into the measure by a shovel, with some force, but without pressing them down.

(249) I have before mentioned (20), that the natural water cements of England, since most improperly and absurdly termed *Roman Cement*, of which the properties were first discovered by Mr. Parker, who took out a patent in 1796 for the

exclusive use of them, had superseded the Trass of the Rhine, vulgarly termed Dutch Terrace, and the Puzzolanas of Italy. This assertion is perfectly accurate in respect to private works in the neighbourhood of London, and perhaps throughout England generally, and also so far as regards the use of trass, but not so in respect to puzzolana; for I find, on more minute inquiry, that this substance, in combination with some sort of hydraulic lime, has frequently been used, and generally in preference to cement, from the time of Smeaton to the present day, in public works of importance, such as Lighthouses, Harbours, Docks, &c., where strong hydraulic mortar was considered necessary.

(250) It is well known that puzzolana in itself has no cementing properties, having been found, when analyzed chemically, to consist of the same component parts as the coloured clays of nature, that is, chiefly of silica and alumina, with a small proportion of the metallic oxides, and sometimes also with *a Trace* of lime; but when mixed with the weaker hydraulic limes, or even with common lime, it constitutes a hydraulic mortar, that sets under water, certainly much more slowly than either the natural or artificial water cements; but those who are advocates for the use of this substance, consider it not less efficient or powerful in the end. I must confess that I entertain some doubts of the accuracy of this opinion, but as nothing can decide the question but a sufficient number of trials of the strength of cement joints and of puzzolana joints, which would require several months or perhaps a year to accommodate the latter, being the slower setting substance of the two, it is useless to discuss it.

(251) The following is a statement of the various mortars used by Smeaton, in which puzzolana was one ingredient.

SMEATON'S HYDRAULIC MORTARS FOR VARIOUS PURPOSES, COMPOSED OF ABERTHAW OR OTHER WATER LIME, MIXED WITH PUZZOLANA, OR WITH PUZZOLANA AND SAND.

No.	Name of the Mortar.	Winchester bushels by stricken measure of			No. of cubic feet.	Expense per cubic foot.	
		Slaked Lime Powder.	Puzzolana.	Common Sand.		*s.*	*d.*
1	Edystone Mortar...........	2	2	..	2·32	3	8
2	Stone Mortar	2	1	1	2·68	2	1½
3	„ 2nd sort.......	2	1	2	3·57	1	7½
4	Face Mortar	2	1	3	4·67	1	4
5	„ 2nd sort	2	½	3	4·17	1	1
6	Backing Mortar	2	¼	3	4·04	0	11

Smeaton states, that according to the common mode of mixing hydraulic mortar in his time, which was done by continually beating it, one whole day's work of an able-bodied labourer was required for incorporating any of the mixtures above described, or any other well proportioned mixture, containing two bushels of lime as one ingredient; but by adopting a more judicious mode of mixing the ingredients proposed by him, he states that the time necessary for beating them might be reduced one-half. This process of beating he considered indispensable.

I do not understand what he meant in the above Table, by *Stone Mortar*, as distinguished from *Face Mortar;* but since the proportion of lime is the same in all, and we know that he considered the Edystone mortar No. 1, consisting of lime and puzzolana alone, without any sand, as being the strongest hydraulic mortar that could be made, it follows that he must have considered No. 6, which contains the smallest proportion of puzzolana, and the greatest of sand, as the weakest of all; the others being of intermediate qualities, better or worse, as they approximated more nearly to the former or to the latter of those mixtures. It may also be inferred, that he did not think it prudent, in making hydraulic mortar, to use more that 2 measures of sand and puzzolana inclusive, to 1 measure of slaked lime powder.

(252) In building the Bell Rock Lighthouse, opposite to the mouth of the river Tay, Mr. Stevenson used the same sort of lime that Smeaton had done, the blue lias of Aberthaw, in the proportion of 1 measure of quick-lime powder, 1 measure of puzzolana, and 1 measure of sand, which he says that he considered equally good, and of course much cheaper as a hydraulic mortar, than the Aberthaw lime mixed with puzzolana alone would have been, the latter of which substances then bore an exorbitant price. He states that it was not his wish at first to have used Aberthaw lime, but he found on trying the best limes which the neighbouring counties of Edinburgh, Haddington, Fife, and Forfar, could produce, that the like mixtures of these limes, with puzzolana and sand, would not set under water at all.

I am not aware that any other Civil Engineers of this Country have ever dispensed with sand entirely, as Smeaton did in the construction of the Edystone Lighthouse. But in determining the proportions of their hydraulic mortars, I rather suspect, without being certain as to the fact, that some of them have mixed their lime and sand in the same proportions that they considered proper for the mortar of buildings exposed to air only, to which they added the puzzolana, under an impression that since this substance improves lime, it may improve mortar also. Smeaton seems to have apprehended, and I think justly, that the addition of puzzolana, which has nothing calcareous in its composition, over and above as much sand as any lime made up into mortar can well bear, might have the same injurious effect in weakening if not ruining that mortar, as if an additional quantity of sand had been used; and therefore he lays down a rule, that whatever proportion of sand is known to make good common mortar with any sort of lime, the quantity of puzzolana used to improve this mortar, and render it fit for hydraulic purposes, must be deducted from the said proportion of sand.* Puzzolana communicates to limes the property of gradually setting under water; but it may be considered sufficiently proved, that this property does not convey the power of bearing much sand also, by the circumstance, that the powerful water cements of England, possessing much stronger hydraulic properties than any limes we know, are deprived of their adhesiveness, by a smaller proportion of sand, than that which common lime will bear (56 and 57). Hence, by analogy, I consider that the quantity of sand ought not to exceed that of puzzolana or of artificial puzzolana, in mixing these substances with lime, in order to obtain a hydraulic mortar. On this subject, however, I speak with less confidence, because I have tried so few experiments with puzzolana, that I do not feel myself competent to give a decided opinion; which I have no hesitation in doing, as far as the natural and artificial cements are concerned.

REMARKS ON PUZZOLANA. EXPERIMENTS ON THIS SUBSTANCE TRIED AT CHATHAM IN 1829 AND 1837.

(253) It appears from Vitruvius, that the properties of puzzolana were well known, and that it was in common use amongst the Romans, in his time.† He describes it as a substance in the state of dust or fine powder found in the

---

* See the Article on puzzolana mortar, at the end of the third volume of Smeaton's Tracts, published in 1812.

† In Book ii. chap. 6, in which he treats "de Pulvere Puteolano et ejus usu," he commences thus:

"Est et genus pulveris, quod efficit naturaliter res admirandas. Nascitur in regionibus Baianis et in agris municipiorum, quæ sunt circa Vesuvium montem, quod commixtum cum calce et cæmento, non modo cæteris ædificiis præstat firmitates, sed etiam moles quæ construuntur in mari, sub aquâ solidescunt." The word 'cæmentum' is here supposed to mean small stones. It certainly does not imply what we term cement.

neighbourhood of Baiæ and in the environs of Mount Vesuvius, which, when mixed with lime, increased the strength of the mortar of common buildings, and caused that of moles or piers run out into the sea to indurate under water.

(254) After my experiments, tried with the view of obtaining an artificial cement, had first been attended with some success in 1828 and 1829, I procured some puzzolana, that had been provided for the extensive new works then in progress in His Majesty's Dock-yard at Sheerness, in order to experiment upon it, and compare its hydraulic powers with those of the Sheppy and Harwich cements, and with my own artificial cement. All my efforts at that time to produce a good hydraulic cement with puzzolana failed, in consequence of two errors in my mode of using it, which are injurious to its powers.

In the first place, I used the puzzolana in the same state in which I received it, that is, with a very small portion of it only in dust, the rest being in lumps of various sizes, like a mixture of coarser and finer sands, in which state it does not combine properly with lime; for in order to produce that intimate union of the two substances, which alone can prevent the lime from going to pieces under water, it is absolutely necessary that the puzzolana should first be reduced to the state of an impalpable powder, which rule was not mentioned to me by the gentleman at Sheerness from whom I received the article, and which possibly might not have been known, even to the persons employed there in making it into mortar.*

Secondly, I ought to have slaked the lime completely, before I put it under water, instead of which I pounded the lime, but not the puzzolana, in a mortar, after which I mixed the quick-lime powder and the coarse puzzolana into a paste with water, and made balls of the mixture, and put them under water immediately, which is a test that nothing but the strongest water cements will bear.†

---

* Because the puzzolana was thrown in its natural state into a mortar-mill, worked by steam, and having two very heavy iron rollers, under which, whilst being mixed with the lime and sand, this soft substance could not fail to be ground as fine as was necessary, to make it combine properly with the lime. But unless Mr. Rennie had explained, that not merely mixing but grinding was his object in using the mortar-mill, this may have escaped the observation of the persons employed.

† In Smeaton's Observations on Water Cements, he does not lay down either of these rules pointedly; but his practice involved both, for he worked up his experimental mixtures so long, that the lime must have become thoroughly slaked; and in mixing his puzzolana mortar for practical purposes, the continued beating could scarcely have failed to reduce the puzzolana, if coarse, to a very fine state.

(255) In more recent experiments with the same puzzolana, which had remained in my possession since 1829, I reduced it to the state of impalpable powder, and then mixed it with chalk lime perfectly slaked, in the proportion of 2 measures of puzzolana to 1 measure of chalk lime putty. I then put this mixture into a small basin, of which it occupied the bottom, its own upper surface being pressed down level. At the end of about an hour, I poured water gently into the basin until it was nearly full. In this state the puzzolana mortar became harder every day, and on the fourth day after immersion it resisted the pressure of the finger, so that the surface was fairly set.

(256) I also mixed one measure of thoroughly slaked chalk lime putty, one measure of pulverized puzzolana, and one measure of sand together, and treating them precisely in the same manner, I found that the puzzolana still prevented the lime from going to pieces or dissolving under water, but that the sand injured the compound by retarding the setting of it, which after 11 days was only just commencing at the surface; but on handling it rather roughly in trying its hardness by pressing the finger into it, the sort of skin at the surface broke, and the mass below proved at the time to be in a very soft state, like wet clay. On breaking the former mixture of lime with puzzolana, on the same day, to examine its comparative state, we found that it was formed into a cake hardest at the surface, but not soft in the centre, for on breaking off and bruising a small piece, it was reduced to a dry powder.

OF ARTIFICIAL PUZZOLANA.

(257) The most ancient sort of artificial puzzolana is brick-dust or tile-dust, or fragments of pottery ground to powder, which being mixed with lime produce a sort of cement, much more impervious to water than common mortar of lime and sand, and which in all probability was in common use in the time of the Romans, as may be inferred from some passages of Vitruvius.[*] It is not to be wondered at, that men previ-

---

I suspect that this effect was the chief advantage derived from the beating, and that the reason for it assigned by Smeaton, in his Account of the Edystone Lighthouse, was of very secondary importance.

[*] In Book vii. chap. 4, entitled "de Politionibus in humidis locis," he commences thus:

"Quibus rationibus siccis locis tectoria oporteat fieri dixi, nunc quemadmodum humidis locis politiones expediantur, ut permanere possint sine vitiis, exponam. Et primum conclavibus, quæ plano pede fuerint ab imo pavimento alte circiter pedibus tribus, pro arenato testa trullissetur, et dirigatur, uti eæ partes tectoriorum ab humore ne vitientur."

ously acquainted with the use of puzzolana should have had recourse to this expedient, or that it should often have succeeded, since some of the natural puzzolanas and brick-dust not only resemble each other strikingly in their appearance, but modern chemistry has enabled us to ascertain that they contain the same component parts, both being originally clays, and both moderately calcined or burned—the one by volcanic agency, and the other in a kiln or clamp.

This primitive sort of artificial puzzolana has been in constant use from time immemorial in the South of Europe, and especially in France, where the word *Ciment* has been applied to it, which, wherever it occurs in any French writer on Practical Architecture, without farther specification or explanation, invariably and exclusively means brick-dust or tile-dust proposed to be mixed with lime, for the purpose of forming a hydraulic mortar;* and I believe that the same practice has been followed in most of the other countries which formed a part of the Roman Empire.†

(258) Instead of confining themselves to the use of pounded bricks or tiles, the Dutch, to whom hydraulic mortars must have been of peculiar importance, have long been in the habit of burning a clay found under the sea on their coast, for the purpose of forming an artificial puzzolana, which is said to have been so good an imitation of the natural trass of Andernach on the Rhine, that it has been sold for such; and probably some of the Dutch tarras imported into England may have been of this description. More recently, since chemistry became generally known, a number of men of science, especially in France, have in like manner attempted to form more perfect artificial puzzolanas than the indiscriminate use of

---

The word *Testa* is translated by M. Rondelet as *ciment de tuileaux*, and I think he is quite right in this interpretation, for it is evidently contrasted with *Arenatum*, which is mortar composed of lime and sand, and therefore *Testa* must mean mortar composed of lime and tiles or pottery, reduced by grinding to at least as fine a state as sand, if not to impalpable powder.

* This term will probably become obsolete in France, as M. Vicat, who has already improved the French nomenclature of calcareous cements by introducing the term hydraulic lime, instead of a less appropriate expression formerly in use, generally employs the phrase artificial puzzolana in preference to *Ciment*.

† The first works of which I had the entire personal superintendence, instead of attending by routine of duty, were two martello towers built at Sanitje and Adaya, on the coast of Minorca, in 1801. The small cisterns of these towers, and the larger cistern for the signal station of Mount Toro, which was also under my charge, were all lined by the native masons employed in building them, with a mixture of common lime and tile-dust, according to the custom of that island, handed down to them no doubt from the time of the Romans, which was suggested by them, and approved by the Commanding Engineer, my Superior Officer.

tiles or bricks was likely to afford, by burning various natural substances, such as clays, basalts, schists, &c., for this special purpose, of which Mr. Baggé, of Gottenburgh, is said to have been the first to set the example in Sweden, about the middle of the last century. In this important research, M. Vicat, who also made an artificial hydraulic lime, and General Treussart, have exerted themselves with the greatest zeal.

(259) The expedient of using pounded bricks or tiles as an artificial puzzolana was not unknown in England, as appears by a treatise on brickwork published by Mr. Batty Langley, about the middle of the last century, but seems to have been little used. About twelve years ago, Mr. John White recommended the use of pounded bricks burned to a state of incipient vitrification, usually termed *Clinkers*, under the title of British Puzzolana, which does not appear appropriate when applied to an expedient that had been in general use in Europe for twenty centuries. His proceedings, which attracted a good deal of notice in London at the time, will be described in the Appendix. The system suggested by him has not however been adopted in practice, being infinitely inferior to cement for difficult and critical works, and the extra expense of his pounded clinker bricks not being considered sufficiently compensated in domestic buildings by its superiority over common mortar, made of the same limes mixed with sand alone.

EXPERIMENTS ON ARTIFICIAL PUZZOLANA TRIED AT CHATHAM IN 1837.

(260) In these experiments, which were few in number, I caused some blue alluvial clay of the Medway, and some of the brown pit clay of Upnor, which had both been used by me as ingredients for my artificial cements, to be made up into balls and moderately burned; so that when reduced to impalpable powder and mixed with water they would not readily fall to pieces, though they had lost their original plasticity, which degree of calcination appeared to assimilate them as nearly as possible to the natural puzzolana then in my possession. On mixing each of these two calcined clays, after pounding them in a mortar, with common chalk lime perfectly slaked, and made up into a paste with water, in the proportion of two measures of calcined clay powder to one of lime putty, the mixture being worked up into a stiffish paste, we found that the artificial puzzolana produced from the blue clay set nearly, but not quite as quickly under water, as the natural puzzolana, but that produced from the brown pit clay set much more slowly. We also mixed each of these two

artificial puzzolanas with common chalk lime putty and sand, in equal proportions of all by measure; and as these mixtures were made up on the same day, with the like mixtures of the natural puzzolana, before described, we compared them all daily, and found that they set as follows:—first, the natural puzzolana and lime; secondly, the calcined blue clay and lime; thirdly, the calcined brown pit clay and lime; fourthly, puzzolana, lime and sand; fifthly, the calcined blue clay, lime and sand; and lastly, the calcined brown clay, lime and sand. The second mixture, namely, the calcined blue clay and lime, was setting like the natural puzzolana in the most promising manner, though more slowly, forming, like it, a cake hard at the surface; but on breaking it, when eleven days old, to compare it with the former, I found it rather soft in the centre. The cake formed of the calcined brown clay and lime was softer than either of these two, not being quite hard even at the outside, but was superior to all those mixtures, even to that of the natural puzzolana, in which sand as well as lime had formed a part. These last had scarcely begun to set, even at the surface, on the eleventh day, when on breaking them, the inside of the best of them was like moist clay.

(261) From these experiments, I think it probable that the same sort of clay which makes the best ingredient for an artificial cement, when mixed with chalk previously to calcination, will also make the best artificial puzzolana, when calcined separately; and therefore, that pounded bricks, which are always the produce of the coarsest clays, must be much inferior to any of the finer clays for this purpose.

(262) So far as regards the water-setting properties of hydraulic mortars, experiments on a small scale, such as have been related in the preceding articles, are only decisive in respect to the mortar in and near the outside of walls exposed to immediate and continued immersion; for experience has proved that hydraulic mortars, not capable of resisting the immediate and constant action of water in mass, will set in the centre of walls whose surfaces are exposed to it, provided that these surfaces be protected by cement. Thus for example it was found necessary to protect the puzzolana mortar of the Edystone Lighthouse, and of the Bell Rock Lighthouse, by pointing the external joints of the former with gypsum as a temporary expedient, until the mortar should set, and of the latter with cement, these being exposed to the direct wash of the sea; whilst it was also found necessary to protect the blue lias lime mortar of the lower part of the piers of the Menai Bridge, and of the Steam Packet Landing

Wharf at Hobbs' Point, Milford Haven, by cement. In short, no substance with which I am acquainted, excepting cement, is capable of resisting the violence of the waves or of running water; but both puzzolana mortar as well as blue lias mortar without puzzolana, are capable of setting under water in a more tranquil state, but not without the gradual degradation of all the external joints, to a certain distance in; as was exemplified in the experiment with the blue lias mortar, before mentioned (247), of which the inside gradually set, whilst the surface gave way; and from my own experiments with small specimens of the Rosehill lime, and from Smeaton's favourable opinion of the Barrow lime, I consider it probable that the mortars of these two limes also, mixed with a moderate proportion of sand alone, will set in still water, like the blue lias; but so far as regards the weaker hydraulic limes, such as the Dorking, Halling, &c., I do not think that the mortars of any of these limes will set in a satisfactory manner under water, in less than 20 years, unless they either be improved by a proportion of puzzolana, or confined to the middle of the wall only, the two sides being built with cement, or with some much stronger hydraulic mortar to protect the centre.

DESCRIPTION OF THE MORTARS USED IN THE CONSTRUCTION OF THE DOCKS OF KINGSTON-UPON-HULL, AND OF THE STATE WHICH THESE MORTARS HAD ATTAINED, WHEN EXAMINED BY MR. TIMPERLEY, ABOUT HALF A CENTURY AFTER THE FIRST OF THEM, THEY HAVING ALL BEEN BUILT AT DIFFERENT PERIODS, WAS FINISHED.

(263) My doubts on this point have been caused by reading an able and interesting account of the Harbour and Docks of Kingston-upon-Hull, written by Mr. Timperley, and published in the first volume of the Transactions of the Institution of Civil Engineers, from which I shall extract some facts relating to the state of the various sorts of mortar, used in building the walls of the basins and locks of that port.

In building the Junction Dock at Hull, which was commenced in 1826, under the direction of Mr. Walker, afterwards President of the above Institution, it became necessary to pull down a part of the walls of two former docks, in order to form a communication or junction between them by means of this new dock, as its name imports; and at this period Mr. Timperley, the resident or executive Engineer at that port, had an opportunity of examining the mortar of those walls. Of the two original docks, one was called the Old Dock, communicating with the river Hull, which was planned by Mr. Grundy and finished in 1778, after four years' labour; whilst the other, called the Humber Dock, communicating with the harbour on the river Humber, was planned by Mr. Rennie and Mr. William Chapman, of Newcastle-upon-Tyne, jointly, in 1802, commenced next year, filled with water in December, 1808, and opened for business in about six months afterwards.

(264) The basin walls of the Old Dock were built entirely of brickwork with a stone coping, laid in mortar composed of Warmsworth lime and sand, part of which was fresh water sand, the rest selected from the excavation.

The basin walls of the Humber Dock were also built of bricks, with the exception of a stone *thorough Course* at the bottom of the vertical fender piles, three courses of stone on the level of an average tide, the lowest of which was a thorough course also, and the coping. The mortar was made of Warmsworth blue lime and sharp fresh water sand only. The lime having been ground in its dry state in a mill worked by a steam engine, was mixed with two parts of sand for the front work, and, water having been added, the whole was ground again, and the mortar used immediately afterwards, whilst hot and fresh. The backing mortar was composed of one part unslaked lime to three parts of sand, measured and tempered in the usual manner. The brickwork of the front and back was laid in mortar, the rest grouted in every course. Part of these walls being built a little before winter, the front mortar was affected by the frost, but the joints were afterwards raked out and pointed with puzzolana mortar.

The locks in both of these docks, as being the most important parts of the work and more exposed than the basins, were entirely faced with stone, and fronted with puzzolana mortar, but backed with lime mortar of the quality before described. The front mortar for the Humber Dock was composed of one measure of ground Warmsworth quicklime, two-thirds of a measure of ground puzzolana, and $1\frac{2}{3}$ measure of sharp fresh water sand.

On pulling down part of the Humber Dock at the period before alluded to, Mr. Timperley observes, "that all the puzzolana mortar was found to be exceedingly hard, being both in colour and hardness like a well burned brick, but the whole of the other mortar of that dock, with the exception of a very small portion under an inverted arch, was still perfectly soft, and might have been worked up again, without adding a drop of water."

In respect to the puzzolana mortar in the lock, he observes that it appeared to adhere much better to the brickwork than to the stones, which he seems to consider a defect, but which, as I myself have found greater adhesiveness to stone in puzzolana than in common mortar, I ascribe to the inexperience of the workmen in using it. Now, as the water was not let into this dock or great basin, in building which no puzzolana had been used, until about six years after the work was commenced, which must have been of the greatest use to the mortar, by allowing ample time for a great part of it to set in air previously to immersion, notwithstanding which it appears that even at the end of eighteen or twenty years more, scarcely any part of this mortar had set at all,* I conceive that this proves in the strongest light, the propriety of never using any weak water lime mixed with sand alone for the purposes of Hydraulic Architecture; and the hint was not lost upon Mr. Walker, as will presently be mentioned.

(265) In respect to the great basin of the Old Dock, part of which was pulled down at the same period, "the front of the wall, for about 8 or 9 feet, under the coping, had but an indifferent appearance, the bricks being in many places much decayed and rubbed by the vessels, and the mortar washed out of the joints, but below this, the bricks were generally in a much better state, and the pointing nearly entire. It has been before observed, that the mortar for this wall was made partly from sand dug out of the dock, which was far from being of the best quality; the interior of the wall was grouted, and not very sparingly, as in some places the mortar was found nearly as thick as the bricks. The mortar in the inside of the wall varied very much in quality, according to circumstances. Where the wall was solid and undisturbed, it was very hard, requiring picks, and in many places, sledges and wedges to take it down; but where the wall had given way, or been otherwise disturbed, and cracks and cavities thus caused in the inside, the mortar was in general very

---

* Mr. Timperley explains that the mortar in the front of the wall, which was every where soft, was much out of the joints for 9 or 10 feet from the top. Below this the joints were not wasted, but had thrown out a sort of stalactite or calcareous incrustation that entirely covered the face of the wall. As it appears that these different actions on the external surface of the joints took place, the former above, the latter below the level of the high water of neap tides in the basin, I conceive that the moderate action below may have proceeded from the water in the lower part of the basin not being in motion and continually changed, as in river wharfs, or in piers carried out into the sea, which produces a violent action upon common or inferior mortars. (See Articles 10, 11, and 12.)

soft. This was observed in a variety of places, and it was not uncommon to see the mortar in one part of the wall exceedingly hard and good, and within a few inches from it, where the wall was open and the water had found its way, quite soft and bad, or but little harder than when first built."

(266) The author observes, that such works were almost in their infancy in England, at the time when this dock was built, and, therefore, he considers it upon the whole to be creditable to the Engineer who designed it, notwithstanding several defects, which he has mentioned, such as "the insufficiency of the piling, and the foundation, which was only level with the bottom of the dock, not being low enough, in consequence of which the walls have subsided and been forced forward in several places by the pressure of the earth behind, &c." In the front of the wall, the section of which was in the form of a common sloping revetment, an error was committed, by building the courses of brickwork at right angles to the slope, for about 14 inches, or a brick and a half inwards, beyond which the whole remaining brickwork of the wall was built in horizontal courses. Thus there was one unbroken joint nearly vertical, from top to bottom, throughout the whole extent of the dock wall, than which one can scarcely conceive any thing more injudicious. Owing to this defect in the original construction, Mr. Timperley remarks, that "the parts of the wall were not only unconnected, but in many places entirely separate, so that a rod may be thrust down many feet between them. It was observed, also, that where the wall had given way, it was completely separated from the counterforts, to the extent of one or two feet or more in the worst places, whereby the strength of the wall had been greatly reduced."*

---

* The wall was 34 feet 6 inches high, including the coping, with an exterior slope of 5 feet, built on a horizontal piled foundation. It was 10 feet thick at bottom, and 4 feet 6 inches thick at top just below the coping, with four small offsets in rear in pairs, the first at the height of 10 feet, the second pair at 15 feet up. The counterforts were at clear intervals of 35 feet apart, and of the uniform width of 9 feet throughout. Their length, measured from the back of the wall, was 8 feet at bottom, but only 3 feet 6 inches at the top, which terminated 4 feet below the coping. This diminution was not effected by a slope, but by three steps of equal height and width nearly, at the back of each counterfort. I am of opinion, that no sloping revetment with a horizontal foundation resting entirely upon vertical piles in soft soil like the above, can be considered secure against being forced forwards at top; but I shall not enlarge upon this point, which would lead me away from calcareous cements to another branch of the extensive subject of Practical Architecture.

The lock of this old dock must have been the most defective part of the original design, because the walls had yielded so much in the course of seven or eight

(267) I shall here remark, that though the mortar in the centre of the undisturbed portions of this wall had set into a respectable hardness in about half a century, yet from the state of the same sort of mortar in the Humber Dock, it is probable that the whole of it must have remained soft for at least 20 years, and to this soft imperfect state I ascribe the separations that have been mentioned; for with all the disadvantages of an unbroken vertical joint, which is extremely prejudicial in building with common mortar, the front would never have separated from the body of the wall from this cause, if cement had been used; of which the Thames Tunnel, consisting of many hundreds of vertical joints of this description, affords the strongest proof. (See the second Note to Article 58.) Nor could the dock walls possibly have been forced forward, if laid in cement, without drawing the counterforts along with them, with which, in that case, they would have composed one homogeneous mass, as incapable of separation as solid rock.

(268) The walls of the basin of the Junction Dock, the most recent of the whole, were also built with brickwork, but with a facing of ten courses of stone immediately below the coping. Mr. Timperley observes, that the basin had been begun, and the east wall, in particular, had been finished as high as the stonework, with mortar composed entirely of unslaked blue Warmsworth or Weldon lime and clean sharp fresh water sand, in the proportion of two and a half measures of sand to one of lime for the facing, and three and a half measures of sand to one of lime for the backing. Trusting to the high reputation of these limes, which were considered good water limes in the neighbourhood, Mr. Walker had proposed to build the whole of the basin walls in the same manner; but on breaking into the walls of the Humber Dock, as before mentioned, which brought the striking inferiority of that sort of mortar to light, he directed some experiments to be tried on various mortars, in consequence of which, he ordered the whole front of the remaining part of the Junction Dock walls to be faced with puzzolana mortar, composed of one measure of unslaked blue Warmsworth or Weldon lime, half a measure of puzzolana powder, and two measures of sharp fresh water sand; but he directed the hollow quoins of

---

years after it was built, as to require to be taken down about 12 feet from the top. One side was rebuilt in 1785, and the other the following year. But it does not appear that these repairs were effectual, for it afterwards proved necessary to pull down the entrance lock and basin entirely, in consequence of their very ruinous state, in 1814, and to rebuild both, according to a new design and under the direction of Mr. Rennie.

the lock-gates, as being of more importance, to be faced with one measure of Halling lime, one measure of puzzolana, and two measures of sand.* For the backing of his walls he still continued to use the same sort of mortar with which he had commenced.

(269) In the lower part of the east side of the basin of this dock, where no puzzolana had been used, an important circumstance, not noticed by any former writer, or, at least, new to me, was observed by Mr. Timperley, who states, that "notwithstanding the thickness and solidity of the walls, the water in wet weather found its way through, so that they were exceedingly damp even in front, and in several places the water literally ran down the face of the wall. This was ascribed to the mortar and grout not hardening sufficiently, as in all cases where the front was set in puzzolana mortar, although the walls were a little damp in places, the water never penetrated through."

In respect to the puzzolana mortar of this dock, which Mr. Timperley had an opportunity of examining, when part of the wall was pulled down and rebuilt, in consequence of having been injured by shipping, he remarks, "that it was in a good state, although not so hard in the interior as in front, the mortar in the beds of the stonework also being more indurated, and for the most part adhering better than in the vertical joints," which I ascribe to the former having been stiffer than the latter, which must have been poured into these joints in the state of grout. He also remarks, "that this puzzolana mortar in the front of the walls was in general hard and good, even before the water was let in, the only defective part being in the west end of the dock, where the wall was damp in consequence of its being backed with wet soft earth. Some part of the mortar, also, being used late in the year, was a little perished by the frost, and required fresh pointing."

(270) A similar fact was remarked by the same intelligent observer, on breaking into the walls of the old fortifications

---

* Mr. Timperley states that in the course of the experiments before alluded to, he found that the Halling lime was stronger than the Warmsworth, which he describes as a magnesian limestone, and also stronger than the Weldon or Fairburn limes, none of which, when made into flat cakes with sand, and allowed some days to dry previously to immersion, would ever set under water at all, but dissolved in a few weeks. Hence these limes must be very weak, for the Halling lime itself possesses very moderate hydraulic powers. But the addition of the half measure of puzzolana to one measure of those limes having rendered them rather superior to the Halling lime, and as this mixture with a moderate quantity of sand was not much more expensive, than Halling lime mortar made with sand alone would have been, it was used in preference.

of the town of Hull, supposed to have been built with stone in the reign of Edward II., and repaired and strengthened with bricks in that of Richard II. "The mortar was of two kinds, one composed of lime and sand only, the other of lime and powdered tiles or bricks, with very little sand; both were, with a very few exceptions, very hard, the latter being the more so. The mortar appeared to have been used in a very soft state, or as grout, but by no means well tempered, small lumps of pure lime, resembling hard tallow, being interspersed in great abundance. In three or four of the bottom courses, and 9 to 18 inches in width of the back of the wall, where it was in a damp state, it had not set in the least, and at the bottom, in particular, appeared like pure sand; whilst the neighbouring parts being dry, were particularly hard and united like a rock."

THAT GOOD HYDRAULIC MORTAR SHOULD BE USED NOT ONLY FOR THE FRONT BUT FOR THE BACK ALSO OF THE WALL OF A DOCK, BASIN, OR WHARF, WHEN INFERIOR MORTAR IS USED FOR THE CENTRE, BUT THAT IT IS BEST TO REJECT INFERIOR MORTAR ALTOGETHER, AND TO USE GOOD HYDRAULIC MORTAR FOR THE WHOLE WALL.

(271) The propriety of never using common lime mortar, or even the weaker hydraulic limes and sand alone, for the whole backing of the walls of a dock, basin, or wharf, appears to me to be sufficiently proved by some of the facts quoted from Mr. Timperley, which I shall here recapitulate; first, by the penetration of water from the rear, through the entire thickness of the east wall of the Junction Dock whilst in progress; secondly, by the imperfect state even of the puzzolana mortar in front of the west end of the dock, from the same cause; and thirdly, by the mortar in the back of the wall of the fortifications of Hull not having yet begun to set, though part of it must be at least five hundred years old.

(272) Mr. Timperley's description of the state of induration, in which the various sorts of mortar used in the walls of the docks of Kingston-upon-Hull were found, when examined by him at various periods, from one or two years to nearly half a century after they were built, may be considered a record of experiments on a great scale, and of the most convincing nature, upon the fitness or unfitness of these mortars for the purposes of Hydraulic Architecture: and the same most liberal and useful Institution, which has been the medium of laying so much valuable information before the public, will probably be the channel of future communica-

tions of the same interesting nature, respecting the state of similar works in other parts of the United Kingdom, which will afford far more satisfactory data for future hydraulic constructions, than any experiments on a smaller scale can possibly do. One thing only is wanting to render such observations complete, as far as they regard the mortar of new wharf or dock walls. That is, to ascertain the time in which each sort of mortar sets, in the centre of such walls, at a certain distance below the usual level of the mass of water acting on the front of them. For this purpose, it appears to me that the only satisfactory mode will be to cut a small opening into the back of the wall for about 3 feet in, by working from the bottom of a shaft sunk in rear of it. Let this be done in about a year after the dock has been filled with water, or the wharf finished; and when the state of the mortar has thereby been examined, let the opening be filled with brickwork and cement. If the mortar should not have set at this time, similar small openings may be made afterwards for the same purpose, at successive periods of not less than 6 nor more than 12 months, until it shall have set.

(273) In objecting to the use of mortar made of any of the weak hydraulic limes, such as the Warmsworth lime, which appears not to be much better than chalk lime, for the whole backing of walls exposed to water in front, and to damp earth in rear, let it be fully understood that I do not speak in the spirit of criticism, or in depreciation of the eminent Engineers, who have occasionally adopted this practice; for I should have done the same myself in their place, never having seen any objection to it, until after the perusal of Mr. Timperley's valuable, but very recent paper. And I am even aware, that in one instance at least, namely, in the wall of the London Docks, the backing of which was built with mortar said to be composed of 2½ measures of sharp sand to 1 measure of Dorking lime, this sort of mortar proved to be in a very hard and satisfactory state, when part of the wall was pulled down in 1828, of which I was myself a witness. But as these Docks were built about twenty-five years before this partial demolition took place, we do not know how long the mortar may have taken, to acquire the respectable state of induration, in which it was found at the period alluded to.*

---

* The facing mortar of this dock, which was I believe planned by Mr. Rennie, consisted of 1 measure of Aberthaw lime, ½ measure of puzzolana, and 1½ measure of sand, being precisely the same as Face mortar No. 4, proposed by Smeaton in his Table of Mortars (251). I had this information from Mr. Palmer, Engineer of

(274) But if the practice, which has been proved to be generally objectionable, be set aside for the future, and the system of protecting not only the front but the back also of every such wall with strong hydraulic mortar, such as cement or puzzolana, be considered essential; it may be remarked that the curved leaning revetments, usually adopted by the Civil Engineers of this country, for the profiles of their dock walls, have either been made of the uniform thickness of 6 feet from the bottom upwards, or seldom exceeding 8 feet near the bottom, and 6 feet at top, and the counterforts, usually placed at clear intervals of 15 feet apart, have sometimes been made 3 feet, and never more than about 4½ feet square.[*] Hence if we suppose that 2 feet

---

the London Dock Company in 1828, who was then building a new basin, in preparing for which, part of the old wall alluded to was taken down.

[*] For example, the Humber Dock wall, planned by Mr. Rennie, is 32 feet high, including the stone coping, with a concave exterior slope described by an arc of a circle, of which the greatest horizontal ordinate to the said absciss of 32 feet is 6 feet 8 inches. The foundation of the wall and of its counterforts was laid out in an inclined plane, higher in front than in rear, which in profile is represented by a line converging towards the centre of the above-mentioned arc. This plane is at right angles to the sloping piles previously driven, consisting of a line of sheeting piles in front, and of two rows of common piles parallel to these, at central intervals of about 3 feet apart, except where there are counterforts, under each of which there are two more piles forming a fourth row at unequal intervals. A longitudinal waling is spiked along the heads of the sheeting piles, and sleepers upon the heads of the others, supporting transverse close planking, upon which the foundation of the brickwork was commenced.

This profile proved scarcely strong enough, inasmuch as Mr. Timperley observes, that even before the walls were raised to their full height, it was found that they "had been forced forward on the east and west sides near the middle, 2 feet from a straight line, carrying the foundation piling along with them." These appear by the plan to be the longest sides of the Dock. "As a security, a quantity of earth about 10 feet high in the centre, diminishing gradually to 6 feet at each end, was immediately laid in front, where it still remains. A length of the upper part of each wall was also taken down and rebuilt in a straight line. Some time after the Dock was finished, the water having been drawn down to within 13 feet of the bottom, for the purpose of making a level bed for the counterbalance weight of the gale chains, the east wall again gave way a little, but the movement ceased on the rising of the tide. The circumstance operated as a warning not to draw the water so low in future." I conceive it probable, that if the walls had been built with cement, they might have resisted the pressure of earth, to which, with common lime mortar, they were evidently unequal, except when that pressure was counteracted by the water with which the dock was filled. A similar change of form, but of less importance, took place in the centre of one of the long sides of the great basin in Sheerness Dock-yard from the same cause, on letting out the water, after the basin had been kept for some time full.

The wall of the Junction Dock, planned by Mr. Walker, is also a curved leaning revetment, but of a much stronger profile than the above, though some feet lower, having its height or absciss equal to 27 feet 6 inches, and its greatest ordinate or extreme slope 5 feet. It is 10 feet thick at bottom, from whence it is reduced to 8 feet 7½ inches by footings or offsets at the height of 2 feet; and from thence to 6 feet at top, partly by gradual diminution, and partly by four small offsets, the of the wall in front, and 2 feet in rear, including the back and sides of the counterforts, are to be built with strong hydraulic mortar, there will remain so small a space in the centre of the wall for the inferior mortar, that a query naturally suggests itself whether it is worth while to use it in such works at all. I think not: for although there can scarcely be a doubt, that inferior hydraulic mortar will set in time in the centre of a wall, when protected on each side, yet there are objections to this construction; partly from the difficulty of bonding the work properly in those parts, where the different sorts of mortar meet, and partly from the probability of unequal settlements taking place, in a wall built of inferior and consequently very slow setting mortar in the centre, and of superior and very quick setting mortar on each side.

(275) Upon the whole it appears to me, that it is a much sounder principle, to build the entire mass of every dock or wharf wall with one and the same sort of hydraulic mortar throughout, which may either consist of cement powder measured lightly, and sand, in equal measures, or of the best blue lias lime as it comes from the kiln, and sand, in the proportion of 2 measures of the latter to 1 of the former;* or if any inferior lime be used, let it be ground to powder, and mixed with puzzolana also ground, in equal quantities of 1 measure of each, to which, agreeably to an opinion before expressed (252), and in reference also to farther experiments

---

two lowest of which are placed at about two-thirds of the height of the wall, and the others 3 feet higher. The counterforts, parallel in profile to the back of the wall, and with similar offsets opposite to the former, are 4 feet 6 inches square above the height of 2 feet. The foundations are oblique and supported by inclined piles driven at a slope of 2¼ inches per foot. There are four rows of common or bearing piles, the first not far from the front of the wall, the fourth under the backs of the counterforts, with the intermediate rows at equidistant transverse central intervals of 4¼ feet apart, but longitudinally they are only 3 feet apart. The fourth is not a continued row like the others, there being only three piles under each counterfort. Before the first row of those piles, and connected to it by an intermediate waling, a line of sheeting piles has been driven under the whole front of the foundation. Transverse half timbers, and over them longitudinal planks, are fixed over the heads of the piles, forming a sort of grating, below which 18 inches of brick rubbish grouted was laid in the intervals between the piles, as the commencement of the foundation, and a similar concrete was laid at the foot of the wall and covered with earth.

* Mr. Stevenson was induced from his experiments on a small scale, to form an opinion that no mixture of puzzolana and sand, with any common lime whatever, would make a good hydraulic cement, and therefore he used Aberthaw lime, which was much stronger, and which, if protected at the surface by cement, would have set without any puzzolana at all. I think it probable, that his mode of experimenting, like that which I adopted myself at first, must have been rather too severe a trial of the hydraulic properties of mortars, for my own more recent

with puzzolana, that will afterwards be related, I recommend that only 1½ measure of sand shall be added. Except in working with cement mortar, the outer joints will in process of time be washed out or deteriorated for some little way in, which must happen in wharfs executed by tidework. In this case it is best to wait till the defect gradually takes place, at which period the wall will also have settled its utmost, and then let the damaged mortar be raked out, and the joints pointed with cement. In similar dock walls built by means of cofferdams, let the pointing of the external joints with cement be executed just before these dams are removed, at which period in all probability the full or final settlement of walls, built as supposed with blue lias lime mortar, or with the mortars of weaker limes and puzzolana, will have taken place; because the quick setting properties of these mortars put an end to this process much sooner, than in common mortars, composed of weak hydraulic limes or of common chalk lime and sand alone.

(276) For my part, I consider good cement as affording the most perfect sort of mortar for all walls of the description now under discussion, and this opinion is borne out by Mr. Timperley's description of the only part of the works of Hull where cement was used, namely, in a slip for repairing the mud boats and the lock-gates, which was built in 1829 on the west side of the entrance basin, abutting upon the Humber. He remarks that the "the coping and front brickwork of this slip were set with Parker's cement and sharp fresh water sand in equal proportions, and although exposed to the waves and swell of the Humber, have stood hitherto with scarcely a failing joint."

---

experiments at Chatham, tried in a different and less rigorous mode, establish the fact of puzzolana communicating the important property of setting under water to common chalk lime, and Mr. Timperley's reports upon the works at Hull, prove in a more decisive manner, that a smaller proportion of puzzolana than I would myself recommend, imparts the same valuable property to the Warmsworth lime, which from his description I consider to be very little superior to chalk lime.

END OF PART I.

(All that was published)

& F.N. SPON,
3, *Bucklersbury*
LONDON.

This book should be returned to the Library on or before the last date stamped below.

A fine of five cents a day is incurred by retaining it beyond the specified time.

Please return promptly.

DUE [illegible] 14 1926

DUE OCT 27 1925

Eng 638.47
Observations on limes, calcareous c
Cabot Science 006269225
3 2044 091 858 845